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The Qualitative Relation Between Complementary and Contrast Colors

By

Helen D. Cook and Florence M. Kunkel

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THE QUALITATIVE RELATION BETWEEN COMPLEMENTARY AND CONTRAST COLORS

§ 1. Historical summary and statement of problem.

For many years it has been recognized that the qualitative relations between colors, in their "pairing off" as complementaries, contrast colors, and after-images, are much more complex than they were supposed to be at the time of the original formulation of the historical color-theories. The essence of the Hering theory seems to demand that the same colors which pair off as complementaries shall also contrast with each other, both simultaneously and in negative after-images. Yet, after Goethe, it was left primarily to the followers of the Hering school itself to point out the discrepancies between the pairs of complementary and those of contrasting colors. A brief summary of the results reached by previous investigators will furnish the best possible introduction to this report of the Wellesley experiments.

As early as 1810, Goethe[1] noted the most marked of these discrepancies. Blue and yellow, when mixed in the right proportions, give a single sensation of colorless light. But the after-image of the same blue—when produced under the ordinary conditions of a relatively long fixation of a colored surface of medium intensity—is not yellow, but orange. Similarly, the after-image of yellow is not blue, but violet. In other words, the after-images both of blue and of yellow are redder than the corresponding complementaries. Johannes Müller[2] notes the same anomaly in the case of simultaneous contrast colors, as observed in colored shadows.

During the early days of the Hering-Helmholtz controversy the chief question seems to have been the relation between the complementary and the so-called "elementary" or "opposite" colors. According to Hering's physiological theory, the "Urfar-

[1] *Zur Farbenlehre,* Cotta, Tübingen, 1810, pp. 58 ff.

[2] *Handbuch d. Physiol.,* 2, p. 373, 1837.

ben," or introspectively "elementary" and "opposite" colors, red-green, and blue-yellow, should pair off in exactly the same way in the three cases of complementary colors, of negative after-images, and of colors induced by simultaneous contrast. As everyone knows, a long and hot discussion raged between the Hering and the Helmholtz schools about Urgrün and Urrot, which, if "elementary," refuse to be complementary, and if complementary, can, in the present writer's opinion, be called "elementary" only by a vigorous stretching of the introspective imagination. This intractability of Urgrün and Urroth had a two-fold influence on scientific discussion: first, it served to distract the attention of experimenters from the equally interesting if less spectacular behavior of Urgelb and Urblau under certain conditions; and second, it thereby led investigators to place the emphasis on the differences between "opposite" or "elementary" colors on the one hand, and on the other either complementary or contrast colors, rather than on the differences between the two last-named themselves. Hering[3] however, noted that under ordinary conditions of daylight adaptation the negative after-image is not exactly the complementary color, but seems to assume that complementary and "opposite" colors are the same. Later[4] he drops the complementary color from the comparison when he says that the discrepancy between after-image and opposite color disappears under conditions of dark adaptation.

It remained, however, for Tschermak[5] to make a more detailed study of the various color relations involved. Tschermak's work, since in a sense it forms the basis for the present study, must be outlined in some detail. As his title indicates, his investigation is concerned with the relations between "Gegenfarben," or "opposite" colors, complementary colors, and contrast colors, though, like Hering, he is interested rather in the way in which both complementary and contrast colors differ from "opposite" colors, than in the way in which the first two differ from each

[3] *Zur Lehre vom Lichtsinne,* §§ 44, 45, 46, 1874.

[4] Pflüger's Arch. f. d. ges. Physiol. 43, footnote p. 2, 1888.

[5] *Tschermak, A. von, Über das Verhältnis von Gegenfarbe, Kompensationsfarbe, und Kontrastfarbe,* Pflüger's Arch. f. d. ges. Physiol. 117, 473-497, 1907.

other. All his experiments were performed with rotating disks of Rothe colored papers as seen through two apertures in a gray screen in diffuse daylight. In most of the tests the subject fixated a point midway between the two apertures, so that the majority of the experiments deal with slightly extra-foveal vision. The results were the same, however, in the tests made with direct fixation. The "opposite" colors could be determined only for the two pairs of "elementaries," red-green, and blue-yellow. For each pair the two colored disks were varied until the subject declared them to be introspectively "elementary" and opposite in quality. Complementary colors were found by the usual method of matching a color mixture to gray, the color mixture on one disk, the gray on the other. Contrast color for Tschermak usually means the color of the negative after-image, which was determined by projecting the after-image on the gray screen and matching to it a color mixture on one of the rotating disks. His results were:

1. That the subjectively opposite colors are not exactly complementary: "elementary" blue and yellow are made complementary only by the addition of a small amount of red; "elementary" red and green by the addition of a considerable amount of blue.

2. That the discrepancy between contrast colors and opposite colors is in the same direction and still greater in amount; *e.g.* (in agreement with Goethe) the after-image of blue is orange (= yellow + red), of green is purple (= red + blue) etc. In general, that is, the complementary color, and still more the contrast color, differs from the true opposite color by the "subjective addition of a certain amount of red and of blue."[6]

Following Hering, Tschermak explains the differences noted as due to the unequal adaptation of the eye to the different colors, under conditions of ordinary daylight adaptation. He supposes that the daylight adapted eye is in reality adapted to purple (red-blue), and therefore that the complementary and contrast colors take on a purplish caste as compared with the true opposites. Just how or why this purplish adaptation takes place in ordinary daylight is not quite clear. Tschermak explains it as due (1) to

[6] *op. cit.*, p. 487.

the (physical?) color of the daylight itself; (2) to the selective absorption of the diasclerotic light by the pigment of the lens, retinal epithelium, macula, and possibly visual purple. Whether these conditions can really cause an appreciable purplish adaptation of the eye must be left to the decision of the physicists and physiologists.

A second criticism or question which suggests itself to the writers is in regard to the physiological process by which (according to the Hering or any other color theory) adaptation to any color could have just the effect ascribed to it *during* adaptation. Tschermak quotes as substantiating his theory previous work of Hess,[7] in which the latter shows that fatigue for or partial adaptation to a given color makes any other color, seen immediately afterward, tend to take on a tinge of the complementary of the original color. Tschermak therefore argues that adaptation to a given color would have just the opposite effect on the after-image of another color, *i.e.*, would tend to make it take on a tinge of the adaptation color. For example, Hess shows that fatigue for (or partial adaptation to) red makes a blue seen immediately afterward look greenish. The after-image of that greenish-blue might then conceivably look more reddish than the after-image of the same blue under conditions of neutral adaptation. But even if this be the case, it does not necessarily account for the reddish tone of the after-image of blue in the experiments of Tschermak and others. For Hess was experimenting with colors as seen *after* fatigue for a given color, Tschermak with vision *during* adaptation to ordinary daylight, which he supposes to be really adaptation to purplish light. And how far the two conditions are comparable seems to the writers to be extremely questionable. Moreover, whatever effect adaptation may have on the quality of the after-image, unless the illumination is very appreciably altered, it should not influence the quality of the complementary color, as determined by color equations. For, unless psychologists have been mistaken about the laws of color mixture, adding the adaptation color (or its

[7] *Über die Tonänderung der Spektralfarben durch Ermüdung mit homogenem Licht,* Arch. f. Ophth. 36, 1-32, 1890.

complementary) to both of the mixtures forming the equation should not alter the validity of the equation.[8]

Tschermak tests his hypothesis, however, by experiments with artificial adaptation, in which he finds a reversal of the anomaly under conditions of adaptation to yellowish-green. It is to be regretted that these experiments either are so few or are so inadequately reported. The actual results given in the tables show only two tests:[9]

1. On March 27 the subject was adapted to yellowish-green by wearing glasses of that color for half an hour before and during the experiment. "Urblau" was determined, also its complementary, which was found to be "schwach grünlich gelb."

2. On April 30, with the same yellowish-green adaptation, "Urblau" was found, and its negative after-image, which was "grünlich gelb."

These two tests with a single subject seem rather scanty justification for Tschermak's conclusion that "die Kompensationsfarbe (complementary color) weicht von der Gegenfarbe durch Addition eines bestimmten Betrages der Adaptionsfarbe ab. Weit beträchtlicher ist die Addition von gleichfarbiger Erregung im Nachbildprocesse, in der Kontrastfarbe."[10] And not only are these tests insufficient in extent, but the numerical data given lead one to question Tschermak's interpretation of them. One suspects that the subject's adaptation to his yellowish-green glasses was not complete, since the chief difference between the results with and those without artificial adaptation lies in the determination of "Urblau." With normal adaptation the subject judged as introspectively "Urblau" a color made up of blue and green papers in the proportion of 4.2:1 (average of 5 determinations).[11] With yellowish-green adaptation the corresponding proportion is 10:1 (average of 2 determinations). In other words, the blue which looked "elementary" to him under normal

[8] *Cf.* the "third law of color mixture." Titchener, E. B., *Students' Manual Qualitative*, p. 5, 1901.

[9] Tschermak, *op. cit.*, Table III in Appendix.

[10] *Op. cit.*, p. 490.

[11] *Op. cit.*, table 1.

conditions, looked a greenish blue through the yellowish-green glasses, even after he had worn the latter for half an hour. And the blue which he calls truly "elementary" under these conditions looked purplish to him under normal adaptation conditions. Small wonder, then, that the complementary and contrast colors of the second blue are a more greenish yellow than those of the first. For this greenish caste of both the complementary and the contrast yellow is obviously due, not to the artificial adaptation of the eye to the yellowish-green light, but to the more purplish quality of the Urblau determined under these conditions.

The judgment seems inevitable, therefore, that Tschermak's actual results, while they established the fact that under normal conditions both complementary and contrast colors tend to be more purplish than the true "opposite" colors, nevertheless do not justify his theoretical conclusion that these discrepancies are due to the purplish adaptation of the eye in ordinary daylight. A further testing of this conclusion was one of the objects of the Wellesley experiments.

The main purpose of these experiments, however, was the study of that phase of the subject which had been touched only incidentally by other investigators, namely the qualitative relation between complementary and contrast colors. Tschermak, following Hering, laid the emphasis on the differences between opposite colors and complementaries, and referred only incidentally to the quality of the contrast color, contenting himself with the statement that, when the complementary colors vary from the true "opposites," the contrast colors vary "in the same direction" or "still more." His numerical data, however, often show appreciable differences between contrast and complementary colors, and thus agree with the experimental observations in the Wellesley laboratory which originally led the writers to take up this problem. These observations were made during several years' experience in routine color experiments, and seemed to show that the difference in quality between those colors which are complementary to each other, and those which induce each other by contrast, either simultaneous or successive, is much greater than is usually realized. This is especially true in the case of

blue and yellow. The most accurate student-observers in the laboratory found consistently (in agreement with Goethe and Johannes Müller) that the contrast color of yellow is violet, not blue, and that the contrast color of blue is a very reddish orange instead of yellow. The two main problems of these experiments may, then, be stated as follows:

First: To determine the qualitative relation between complementary and contrasting colors.

Second: To determine the dependence of this relation on the conditions of adaptation.

A third problem might be stated as a by-product of the first, namely, the dependence of this relation on the brightness difference between contrast-inducing and contrast-suffering surfaces. The results bearing on the last point, however, though they will be reported in the text below, are not complete enough to be of more than incidental interest.

§ 2. General Method of Experiments.

The main problem, as stated above, is the relative quality of those pairs of colors which are complementary to each other, and those which induce each other by contrast, either simultaneous or successive. The exact quality of the negative after-image is very hard to determine, so that in most of our experiments we confined our attention to the simultaneous contrast color. The method, then, consists essentially in determining as accurately as possible the quality of the complementary, the simultaneous contrast, and, in a few cases, the negative after-image of a given color, and in comparing with each other the results thus obtained. All experiments were made with reflected lights—revolving disks of Hering colored papers seen in diffuse (north-west) daylight. It seems unnecessary to describe in detail the methods used for determining complementary and contrast colors, since these took the orthodox form of making color-equations.[12] In most of the tests the matches were made, as by Tschermak, with slightly excentric fixation. The two disks to be matched ("large" size,

[12] *Cf.*, Titchener's Experimental Psychology, *Students' Manual Qualitative*, pp. 6-7, and 17.

9.6 cm. radius; "small" size, 5.5 cm. radius) were set up on two rotating pivots 32 cm. apart, with a fixation point midway between them. The subject sat at a distance of 2 meters. The angle of eccentricity was therefore $4°35'$. Complementary colors were found by matching a color mixture on one disk to a black-white mixture on the other, both disks large size. In the determination of the contrast color a small disk of black, white, and the necessary colors was matched to the color taken on by a black-white contrast ring on a large colored disk. The contrast rings were 1.8 cm. wide, inside radius 4.7 cm. The brightness of the contrast ring was equal to that of the colored background, as determined by the flicker method,[13] in all tests except those of groups I and II, which were especially designed to test the effect of variations of brightness on the quality of the contrast color.

The subjects serving in the experiments were seven in all: three trained in general experimental work, C. and K., the writers of this report, on whom the large body of the experiments was made, and F., a Wellesley College Senior, who was at the time taking her third course in experimental psychology; and the four untrained subjects, D., H., Ke., and M., undergraduates in a first course in experimental psychology.[14] None of the subjects was especially practiced in color observations. K. was experimenter in all tests except those made on herself, and a few on the observer F. These tests were conducted by C. These two main subjects, C. and K., knew of necessity the purpose and method of the experiments. They took, however, every possible precaution to keep themselves uninfluenced by expectation, including that of examining no results of any subject until the entire series of tests was complete. The subject F. knew of the

[13] Criticisms, from the laboratories of Clark and Bryn Mawr Universities (first communicated to the writers orally. For published results see the Psych. Rev. 22, 1915, 110-162), have not been overlooked, but the method was used for lack of a better one. Since the experiments of Groups I and II seem to indicate that the brightness of the contrast ring has very little, if any, effect on the *quality* of the contrast color, which is the point at issue in these tests, any inaccuracies in the method of equating brightnesses probably do not seriously affect the validity of the results.

[14] To these student subjects the writers take this opportunity of expressing their sincere thanks for the time and patience devoted to the work.

purpose and plan of the work only in the most general way, and the four untrained subjects were entirely "without knowledge." It is needless to add that all other usual laboratory precautions were observed, such as eliminating time and space errors by a compensating order of tests, etc. Minor variations of method for special purposes will be described in connection with the different groups of experiments, and the special method used for the determination of the color quality of the negative after-image, used in the tests of group V, will be given with the discussion of that group.

The tests made fall into the following main groups:

Groups I and II: to determine the general qualitative relation between the complementary and contrast colors, and the dependence of this relation on the brightness of the contrast ring, and on eye-movement.

Groups III and IV: the influence of artificial adaptation to different colors on the quality of the complementary and of the contrast colors.

Group V: supplementary tests with untrained subjects: the relation between complementary, simultaneous contrast, and negative after-image colors.

§3. Experiments. Group I.

The experiments of this group were in several respects rather rough tests, and should therefore be considered as preliminary. The results are given here for two reasons: first, because so far as the methods used agree, these results are essentially the same as the findings of later, more careful experiments; and second, because the tests of this group and of group II include some material not found in the later work. At the outset we hoped to be able to solve simultaneously two problems: the primary problem of the relation of contrast colors to complementary colors, and the secondary one of the possible dependence of the quality of the contrast color on the brightness of the black and white contrast ring in comparison with its colored background. Later, for various reasons, this second problem was dropped. The tests of this and the following group are therefore the only ones in which

contrast rings of varying degrees of brightness were used. The observers of this group were three, C., K. and F. For each of these subjects a determination was made of the complementary and the simultaneous contrast colors of Hering red, yellow, green, and blue, and of the Milton-Bradley yellow. This last color was included because for most observers it is almost the exact complementary of the Hering blue, while the Hering yellow is apparently somewhat too greenish. The difference between complementary and contrast colors comes out therefore especially strongly by using the Hering blue and Milton-Bradley yellow papers, as will be seen from an examination of the results in the following table. With the one exception of the Milton-Bradley yellow all papers used are the Hering standard colors. The first column on the left gives the color whose complementary and contrast colors are being determined. The next column shows the varying amounts of white in the contrast ring. The rest of the ring was black. Then follows for each of the three observers the relative amounts of the two primary colors needed to make the complementary, and the relative amounts of the same (or different) two colors needed to match the apparent color of the contrast ring. In the last column for each observer is stated the direction of the difference between complementary and contrast colors. This form seems the most convenient one for a comparison of results. For example, if for observer C. the average complementary color equation is $52°B + 140°R + 168°G = 88°W + 272°N$ (black), then the complementary of red lies between blue and green in the proportion of 52 of the former to 168 of the latter, or the ratio of blue to green is 0.31. The equations for the contrast colors are treated similarly. For observer C. the color induced by a ring of 40° white *plus* 320° black on a red disk is matched by a disk composed of $9.5°B + 19.5°G + 22.5°W + 308.5$ N. The contrast color is therefore an unsaturated bluish green, in which the blue and green appear in the proportions of 9.5 :19.5, or 0.49. The table of results follows:

TABLE I

Color	Degrees of W in contrast ring	Observer C: Complementary	Observer C: Contrast	Observer C: Direction of Difference	Observer K: Complementary	Observer K: Contrast	Observer K: Direction of Difference	Observer F: Complementary	Observer F: Contrast	Observer F: Direction of Difference
R	40 ← 60 80 100	$\frac{B}{G} = 0.31$	$\frac{B}{G} = 0.49$ 0.66 0.87 0.88	bluer bluer bluer bluer	$\frac{B}{G} = 0.35$	$\frac{B}{G} = 0.38$ 0.31 0.39 0.36	(bluer) (greener) (bluer) (bluer)	$\frac{B}{G} = 0.34$	all B all B all B all B	bluer bluer bluer bluer
Y (M. B.)	200 220 ← 240 260	$\frac{G}{B} = 0.03$	$\frac{R}{B} = 0.42$ 0.39 0.43 0.43	redder redder redder redder	$\frac{G}{B} = 0.04$	$\frac{R}{B} = 1.10$ 1.13 1.02 1.07	redder redder redder redder	all B	$\frac{R}{B} = 0.74$ 0.47 0.47 0.50	redder redder redder redder
Y (H.)	200 220 240 260 ←	$\frac{R}{B} = 0.19$	$\frac{R}{B} = 0.51$ 0.48 0.60 0.62	redder redder redder redder	$\frac{R}{B} = 0.22$	$\frac{R}{B} = 1.30$ 1.31 1.30 1.29	redder redder redder redder	$\frac{R}{B} = 0.18$	$\frac{R}{B} = 0.54$ 0.42 0.38 0.48	redder redder redder redder
G	100 120 ← 140 160	$\frac{B}{R} = 0.37$	$\frac{B}{R} = 0.59$ 0.64 0.64 0.61	bluer bluer bluer bluer	$\frac{B}{R} = 0.43$	$\frac{B}{R} = 0.28$ 0.40 0.45 0.42	(redder) (redder) (bluer) (redder)	$\frac{B}{R} = 0.42$	$\frac{B}{R} = 0.48$ 0.34 0.32 0.34	(bluer) (redder) (redder) (redder)
B (with M. B. Y)	80 ← 100 120 140	$\frac{G}{Y} = 0.04$	$\frac{G}{Y} = 0.81$ 0.65 0.57 0.61	redder redder redder redder	$\frac{R}{Y} = 0.06$	$\frac{R}{Y} = 0.87$ 0.81 0.60 0.55	redder redder redder redder	all Y	$\frac{R}{Y} = 1.02$ 0.97 0.51 0.82	redder redder redder redder
B (with H. Y)	80 ← 100 120 140	$\frac{R}{Y} = 0.28$	$\frac{R}{Y} = 1.24$ 1.04 0.77 0.90	redder redder redder redder	$\frac{R}{Y} = 0.31$	$\frac{R}{Y} = 1.82$ 1.36 1.09 1.15	redder redder redder redder	$\frac{R}{Y} = 0.25$	$\frac{R}{Y} = 1.65$ 1.29 1.25 1.49	redder redder redder redder

Each of the values given in this table is an average of only two determinations.[15] Small variations are therefore of no significance,[16] but the general tendency is unmistakable, and is in agreement with the findings of Tschermak. In all cases, for all three observers, the contrast color has a tendency to be either redder or bluer than the complementary. The only exception is the second value given for the contrast of R. with the subject K., where the difference involved is so slight as to be without significance. The divergence between contrast and complementary color is, however, much more striking with yellow and blue than it is with red and green. Indeed, it practically disappears for both red and green in the case of the observer K., and for green with observer F. For blue and yellow, on the other hand, it is marked for all observers, so much so that the contrast color of blue is orange, or reddish-orange, rather than yellow, and the contrast of yellow is violet. And this is true in spite of the fact that blue and Milton-Bradley yellow are exactly complementary for one observer, and are made so for the other two observers by the addition of a very slight amount of *green*. Hering yellow, as noted above, needs to be changed by the addition of a slight amount of red to make it complementary to the Hering blue, but very much more red must be added before it matches the contrast color induced by the same blue.

So far, then, these preliminary experiments substantiate Tschermak's results that the contrast color is redder or bluer than the complementary, and add to his conclusions that the difference is large in the case of blue and of yellow, while usually very small for red and for green. Later experiments (Groups III and IV) were designed to test Tschermak's explanation of the difference as due to the (supposedly) purplish adaptation of the eye in ordinary daylight. Before passing on to those, however, it may be worth while to devote a little space to the other two questions to which the present group of experiments was

[15] For this reason and because of the preliminary nature of the tests, mean variations are not given.

[16] Parentheses in the table indicate differences between contrast and complementary colors which are certainly too small to be significant.

designed to give at least tentative answers. Those questions are:

First, does the quality of the contrast color vary with variations in the brightness of the contrast ring?

Second, does the amount of contrast induced vary with the brightness of the ring; in other words, is it true that "the contrast effect is greatest when there is no simultaneous light contrast"?[17]

The first of these questions was suggested by the nature of our problem itself; the second arose out of the fact that our laboratory students, using Professor Titchener's manual and textbook, had often been troubled by finding their experimental results not in accord with this "third law of contrast" as quoted above, and this opportunity for testing the law seemed too good a one to be passed by. Unfortunately, however, owing to a mistake of the experimenters, the variations in brightness of the contrast rings were not distributed evenly on either side of the zero point, or point of no brightness contrast. The arrows in the second column of the table already given (p. 15) indicate the points at which brightness contrast between gray ring and colored background has been eliminated, as tested by the flicker method.[18] Owing probably to this defect, or else to the small number of tests made for each average, or possibly to real individual differences, the results for the three subjects agree in their answers to neither of the questions stated above.

In regard to the first question, the dependence of the quality of the contrast color on the brightness of the contrast ring in relation to the brightness of the inducing background, the results are as follows:

For the subject C.: the anomaly (*i.e.,* the difference between contrast and complementary colors) is greatest where there is least brightness contrast in the cases of the colors blue, green, and Hering yellow. With red the anomally is greatest with the lighter contrast rings. Milton-Bradley yellow shows irregular results.

For the subject K.: the anomaly is greatest with the elimina-

[17] Titchener, E. B. *Text-Book of Psychology,* 1909, p. 76.

[18] *Cf.* above, p. 12, footnote.

tion of brightness contrast for the colors blue and Milton-Bradley yellow. Hering yellow shows only slight variations for the different brightnesses, and for this subject the anomaly practically disappears with red and green.

For the subject F.: the results are too irregular to allow of any generalizations.

The only possible conclusion, therefore, seems to be that there is a slight tendency for the difference between contrast color and complementary to increase with a decrease in the brightness contrast between contrast rings and background. In spite of the indefiniteness of this statement, however, the fact must be emphasized that with all three subjects, for the colors blue and yellow where the difference between contrast color and complementary is marked, that difference is independent of any variation in the brightness of the constant ring. The *amount* of the anomaly varies somewhat for the different brightnesses of the gray ring, but it never disappears and is never reversed, and the variations themselves are relatively slight when compared with the large differences between contrast and complementary colors. Whatever the brightness of the contrast ring, the contrast color of blue is always orange, and the contrast of yellow, violet. The conclusion seems justified, then, that the difference between contrast and complementary colors, at least in the cases of blue and of yellow, is independent of any difference in brightness between contrast-inducing and contrast-suffering surfaces.

With regard to the second question stated above, the dependence of the *amount* of contrast color on the presence or absence of simultaneous brightness contrast, the results are somewhat irregular, but are in general in at least partial agreement with the generally accepted law that color contrast is greatest when brightness contrast is eliminated. The amount of contrast is obtained by adding together the number of degrees of contrast color in the original equations obtained. This gives the following:

Table II

Color	Degrees of W in contr. ring	Contrast color	Amount of Contrast C	K	F.
R	40	G + B	29.0	25.5	9.5
	←				
	60		50.5	34.0	8.0
	80		70.0	25.0	5.0
	100		73.5	30.0	14.0
Y (M.B.)	200	B + R	132.7	62.4	50.5
	220		136.4	68.3	53.5
	←				
	240		136.3	69.3	66.0
	260		137.7	81.3	78.0
Y (H.)	200	B + R	114.5	76.0	116.0
	220		132.5	77.5	92.0
	240		146.5	88.5	134.5
	260		147.0	88.0	123.0
	←				
G	100	R + B	92.0	46.0	80.0
	120		119.0	54.0	71.3
	140		114.0	53.0	82.0
	160		101.5	52.0	89.5
B (with M.B.) Y)	← 80	Y (M.B.) + R	95.0	64.5	70.5
	100		108.0	75.0	73.0
	120		100.0	78.5	79.5
	140		108.5	68.0	88.5
B (with H. Y)	← 80	Y (H.) + R	108.5	76.0	65.0
	100		114.0	82.5	99.5
	120		103.5	74.0	121.5
	140		111.0	73.0	81.0

The abbreviations here are the same as those already used in Table I. Again the arrow in column 2 indicates the point at which brightness contrast between gray ring and colored background is eliminated. The law of greatest color contrast when brightness contrast is eliminated seems to hold here only to a certain extent. It is apparently partially counteracted by another tendency, namely, for the lighter rings to suffer greater contrast effect than the darker ones. Owing to the faulty nature of the brightness series for the different colors, the two laws (if the second tendency may be called a law) sometimes work together and sometimes cut across each other. The relative strength of the two laws, and indeed the existence of the second tendency as a general law, can be determined only by further experiments planned for the purpose.

§ 4. Experiments. Group II.

In the experiments of Group I, Tschermak's method in regard to the use of a fixation point was not followed, but the eyes of the observer were allowed to move freely from one disk to the other as he formed his judgments. Tschermak suggests that with free eye-movement after-images may set in and influence the results. Accordingly, in Group II the experiments of Group I were repeated with no other change than the introduction of a fixation-point midway between the two disks,[19] and thereby the elimination of eye-movement. The results are so very similar to those already reported in the experiments of Group I that it seems useless, especially in the case of such rough tests, to give them in detail. They show the same main conclusion as that reached in the preceding experiments, namely, that the contrast color is always either redder or bluer than the complementary. The difference is striking for blue and for yellow, often rather insignificant for red and for green. The only case where the two sets of results are at variance is in the case of the color green for the subject C. In Table I for this subject the contrast color of green is a purple somewhat bluer than the complementary; in the present group of experiments it is slightly redder. It will be noted, however, that in Table I for both the other observers the color green gives irregular results, the contrast color being sometimes redder, sometimes bluer than the complementary. This is, of course, exactly what one would expect if, as Tschermak concludes, and as our results seem to indicate, the physiologically induced contrast of any color has a tendency to take on a more purplish tone than the complementary. Since the complementary of the Hering green is itself purple, its contrast should be the same color, and the irregular variations in the direction of red or of blue are very probably due to accidental variations not eliminated in these rough tests.

The main conclusion of these two groups of experiments is, then, that both in the case of foveal fixation of the colors to be compared, with free eye-movement (Group I), and in that of the elimination of eye-movement with slightly extra-foveal vision

[19] *Cf.*, above, p 7.

(Group II), the contrast color tends to diverge from the complementary in the direction of purple, with the result that the contrast colors of blue and of yellow are much redder than their respective complementaries, the contrast of red is somewhat bluer than its complementary, and the contrast of green is approximately the same as its complementary. The results are thus far in full agreement with those of Tschermak, though, as already noted, his emphasis was on the difference between "opposite" color and complementary, rather than on that between complementary and contrast color.

Before taking up the experiments testing Tschermak's explanation of the anomaly, brief mention may be made of the results of the present group of experiments in regard to the two other questions under consideration in this and the preceding group, *viz.*: the dependence of the quality and of the amount of contrast color on the presence or absence of simultaneous brightness contrast. The results of this group of experiments show somewhat greater irregularities than those of Group I, the simple explanation probably lying in the fact that none of the three subjects tested had had any particular practice in the difficult task of looking at one thing while paying attention to another. The judgments with a fixation-point midway between the two disks to be compared were, therefore, more difficult and were made with much less subjective certainty, in these early experiments, than in the tests without the fixation-point. Gradually, however, all the subjects grew more and more accustomed to the unnatural conditions of the experiment, and in the tests of the later groups the two subjects who served throughout, C. and K., thought the judgments with the fixation-point fully as easy if not easier than those where free eye-movement was allowed.

So far as the values of the contrast color for the different brightnesses of the gray ring show any regularity, they agree with the results of the experiments of Group I: the anomaly shows some tendency to increase with decrease in brightness contrast between contrast-inducing and contrast-suffering surfaces. The values are, however, too irregular to justify any detailed treatment.

The *amount* of contrast induced for the different brightnesses of the contrast ring seems to depend on the combined effect of the two tendencies already noted in Group I (p. 19). The first tendency is that expressed by the standard law of greatest color contrast where there is no simultaneous brightness contrast. The second tendency is for the lighter gray rings to suffer more contrast than the darker ones. The first tendency seems to be especially strong with observer C., the second with observer K. Whether this is a real individual difference or is due to accidental variation; in fact, whether or not the second "tendency" noted above is a real law, could be tested only by further, more exact experiments. The problem was dropped at this point in order that sufficient time might be devoted to the question of the quality of the contrast color, and to a testing of Tschermak's explanation of its deviation from the complementary.

Thus the conclusions reached by the experiments of Groups I and II are as follows:

1. That the color induced by simultaneous contrast, for the three primary colors, red, blue, and yellow, is not the same as the complementary color. The contrast color of red is somewhat bluer than the complementary, and the contrast colors of blue and of yellow are much redder than their respective complementaries. That of green, on the other hand, is approximately the same as its complementary. This may be expressed by saying, with Tschermak, that the contrast color tends to be more purplish in tone than the complementary.

2. That the direction, and to a large extent the amount of the anomaly, is independent of brightness contrast between contrast-inducing and contrast-suffering areas. If anything, the anomaly is greatest when brightness contrast is least.

3. That the amount of contrast induced on the gray ring seems to depend on the simultaneous operation of two tendencies: (*a*) for the color contrast to be greatest when brightness contrast is eliminated; (*b*) for the lighter gray rings to be more subject to contrast effects than the darker ones.

4. That the above conclusions apply equally to foveal vision with free eye-movement, and to slightly extra-foveal vision with eye-movement eliminated.

§ 5. Experiments. Group III.

As noted in § 1, the tendency toward purple shown by both complementary colors and negative after-images in comparison with "opposite" colors was explained by Tschermak, following Hering and Hess, as due to the purplish adaptation of the eye in ordinary daylight, and this hypothesis was tested by experiments with artificial adaptation, which have already been criticised.[20] Whether such an explanation could account for the similar difference, noted but unemphasized by Tschermak, between complementary and contrast colors, was the next problem which presented itself for our consideration. If the adaptation hypothesis is correct, the anomaly in case of the colors yellow and blue should increase with artificial adaptation to red or purple, and should decrease or be reversed with adaptation to green or yellow-green. For the color red, the anomaly should increase with adaptation to blue or purple, and should decrease or be reversed with adaptation to yellow or yellow-green. For the color green the existence of the anomaly (*i.e.*, a difference in quality between complementary and contrast colors) is doubtful.[21] The best method of testing the adaptation hypothesis is evidently, therefore, that used by Tschermak, namely, to repeat with artificial adaptation to different colors all or a part of the tests already made with normal adaptation. Since the anomaly was strongest for the colors yellow and blue, we confined our work in the present group of tests to artificial adaptation to red and to yellowish-green only. The writers were the only observers available for these tests, since the work demanded more consecutive time than the undergraduate subjects could be asked to give. No attempt was made to study further the influence of brightness contrast or of eye-movement on the contrast color, but the experiments were concerned solely with the study of the respective qualities of complementary and contrast colors under normal, red, and green adaptation, with all other conditions as constant as possible. Eye-movement was, therefore, eliminated by the use of the fixation point, and only one ratio of black and

[20] *Cf.*, above, pp. 9-10.
[21] *Cf.*, above, p. 21.

white in the contrast ring was used for each color—that producing a gray of equal brightness to the colored background, as tested by the flicker method.[22] This group, therefore, contains determinations of complementary and contrast colors made with normal, with red, and with green adaptation (rotating according to a compensating program).

The artificial adaptation was obtained, as by Tschermak, by wearing for two hours before and during the experiment colored glasses of red or of green. The glasses used in this group of tests were obtained from an optician and were mounted in ordinary optician's frames. Unfortunately, however, this method is open to several objections. In the first place, normal daylight could reach the eye around the sides of the glasses, therefore the adaptation cannot be considered complete. In the second place, the red and green glasses turned out to be of very unequal strength, though we tried to obtain them as nearly alike as possible.[23] In the third place, because of the greater strength of the green glass, the adaptation to green was, even subjectively, not absolutely complete at the end of the two hours which preceded the actual tests. For these reasons, the experiments of this group should be considered in the light of rough preliminaries to those of the next group, where the colored adaptation was obtained by a more accurate method. The results are included here because they disagree radically with the results of Tschermak obtained under somewhat similar conditions, but agree very closely with the results of the more accurate experiments of Group IV. The values of the complementary and contrast colors of red, Milton-Bradley yellow, Hering yellow, green, and blue for the two subjects C. and K. under conditions of normal, of red, and of green adaptation are given in the following tables. Each ratio as given here is computed from the average of four determinations. Variations in the single determinations are not given, since these tests are preliminary to the more accurate ones of the next group.

[22] *Cf.*, above, p. 12.

[23] As tested later by the Lovibond tintometer the green glass was found to be equal to 0.5 units of blue plus 7.5 units of yellow, the red glass to 1.0 unit of red.

TABLE III. OBSERVER C.

Color	Adaptation	Compl.	Contr.	Direction of Difference
R	Normal	$\left\{\frac{B}{G}\right\} = 0.42$	$\left\{\frac{B}{G}\right\} = 1.06$	bluer
	Red	0.38	0.84	bluer
	Green	0.39	1.05	bluer
Y (M.B.)	Normal	$\left\{\frac{G}{B}\right\} = 0.02$	$\left\{\frac{R}{B}\right\} = 0.53$	redder
	Red	0.06	0.41	redder
	Green	0.01	0.33	redder
Y (H.)	Normal	$\left\{\frac{R}{B}\right\} = 0.20$	$\left\{\frac{R}{B}\right\} = 0.81$	redder
	Red	0.19	0.59	redder
	Green	0.20	0.52	redder
G	Normal	$\left\{\frac{B}{R}\right\} = 0.47$	$\left\{\frac{B}{R}\right\} = 0.28$	redder
	Red	0.49	0.58	bluer
	Green	0.42	0.39	redder
B (with H.Y)	Normal	$\left\{\frac{R}{Y}\right\} = 0.33$	$\left\{\frac{R}{Y}\right\} = 1.82$	redder
	Red	0.28	1.33	redder
	Green	0.30	1.06	redder

TABLE IV. OBSERVER K.

Color	Adaptation	Compl.	Contr.	Direction of Difference
R	Normal	$\left\{\frac{B}{G}\right\} = 0.38$	$\left\{\frac{B}{G}\right\} = 0.61$	bluer
	Red	0.38	0.56	bluer
	Green	0.29	0.58	bluer
Y (M.B.)	Normal	all blue	$\left\{\frac{R}{B}\right\} = 0.62$	redder
	Red	" "	0.60	redder
	Green	$\left\{\frac{G}{B}\right\} = 0.02$	0.66	redder
Y (H.)	Normal	$\left\{\frac{R}{B}\right\} = 0.18$	$\left\{\frac{R}{B}\right\} = 0.62$	redder
	Red	0.23	1.14	redder
	Green	0.20	0.71	redder
G	Normal	$\left\{\frac{B}{R}\right\} = 0.40$	$\left\{\frac{B}{R}\right\} = 0.26$	redder
	Red	0.45	0.26	redder
	Green	0.36	0.28	redder
B (with H.Y.)	Normal	$\left\{\frac{R}{Y}\right\} = 0.28$	$\left\{\frac{R}{Y}\right\} = 1.86$	redder
	Red	0.35	1.62	redder
	Green	0.29	0.92	redder

The results evidently do not verify the adaptation explanation of the difference between contrast color and complementary, since that difference persists in the same direction for red, for green, and for normal adaptation. On the one hand, there is no trace of such a reversal of the anomaly with yellowish-green adaptation as that reported by Tschermak; and on the other, the anomaly for blue and yellow is not appreciably increased by red adaptation, as it should be according to the Tschermak hypothesis. According to that theory, it will be remembered, both complementary and contrast colors, but especially the latter, should become more reddish with red adaptation, and more greenish (or less reddish) with green adaptation. Out of the ten complementary colors determined (five for each observer), there is no case in which the color is more red (or less green) than normal with red adaptation, and more green (or less red) than normal with green adaptation; and of the ten contrast colors determined there is only one case in which this is true (the contrast of Hering yellow for observer K.). The only general tendency that can be detected is for the contrast colors to become somewhat less reddish than normal with *both red and green* adaptation,—a paradoxical enough result! The only possible explanation that would seem to suggest itself is that, since both red and green glasses decrease the amount of light reaching the eye, the *brightness* of the light to which the eye is adapted has more effect on the color quality of the contrast colors than has the *quality* of that light. The differences between daylight and dark adaptation reported by Hering and Hess might, therefore, be explained on some other ground than that daylight adaptation is really adaptation to reddish-blue, as Tschermak supposes. It is, of course, conceivable that the *amount* of light reaching the eye causes qualitative, as well as quantitative, differences in the retinal processes involved, in other cases than the well-known one of twilight vision. At any rate, it is evident that the effect on both complementary and contrast colors of artificial adaptation to different colored lights can be studied adequately only under conditions of equal brightness of light for the different colors. These conditions the experiments of the next group attempted to fulfill.

§ 6. Experiments. Group IV.

These tests repeat those of the preceding group under more exact experimental conditions. The writers, C. and K., again acted as observers. As in the experiments of Group III, eye-movement was eliminated by the use of a fixation point midway between the two disks to be compared, and the contrast ring for each color was of the same brightness as its colored background. The differences in method between these tests and those of the preceding group were the following:

1. Tests were made with artificial adaptation to each of the four primary colors, red, green, blue and yellow, instead of to the first two only.

2. The colored glasses were provided by the Lovibond Tintometer Co. of Salisbury, England, and each glass was of one unit's strength, as measured by their scale. In this way we hoped to reach approximate equality in the brightness of the different colors.

3. The glasses were mounted in black automobile goggle frames which allowed no light to reach the eye except that passing through the colored glass.

4. Adaptation with these glasses was subjectively complete in less than half an hour. The glasses were, therefore, worn for only three quarters of an hour before the experiment, and of course during its progress.

5. Since all these colored glasses change the quality of light reaching the eye by reducing its amount, normal daylight adaptation gives, of course, a different condition of brightness adaptation than do the colored glasses. A fifth pair of goggles was, therefore, made up with glasses of the Lovibond neutral gray of one unit's strength.[24] In the table following, adaptation to these

[24] According to the Lovibond calculations, as we understand them, these glasses should give colors and gray of equal brightness. Actually, however, the green and gray glasses are (both subjectively and physically) darker than the others, since they are not single glasses but are obtained by combinations of the others. Each of the red, yellow, and blue glass absorbs a certain amount of all light except that of the given color. Green, which is made up of the blue and yellow glasses, thus gives a double subtraction of light, and gray (blue + yellow + red) a triple subtraction. It is probable,

glasses is called gray (A) adaptation, while that to ordinary daylight is called normal (N) adaptation.

6. The use of the Milton-Bradley yellow was omitted as an unnecessary expenditure of time, since the Hering yellow brings out the anomaly just as clearly, by the relative *amounts* of red used in the complementary and contrast colors, if not as spectacularly, by the actual reversal of green in the complementary to red in the contrast. All papers used in these tests are, therefore, the Hering colors.

7. In the earlier experiments, the contrast color had seemed to both observers to change, both in amount and in quality, during the time required for the formation of a judgment, becoming both stronger and redder with long fixation. We had no time to test the point by actual experiment, but in the tests of this group adopted, as a precautionary measure, a uniform fixation time, for both complementary and contrast colors, of five seconds. This particular time was chosen as long enough for the formation of an easy judgment, but not so long as to cause fatigue.

Each ratio given is computed from the average of four observations. Mean variations are given in parentheses after each average.

Again the results are negative in regard to the dependence of the difference between contrast and complementary color on the color to which the eye is adapted at the time of observation. For both subjects, with all six kinds of adaptation, the contrast color of red is bluer than its complementary (slightly so for K., very much so for C.), the contrasts of yellow and of blue are much redder than their complementaries, and the contrast of green is approximately the same as its complementary (somewhat redder for one subject, equal for the other). It will be

therefore, that we should have had more nearly equal brightness conditions if we had used, for example, blue, yellow, and red of 6 units' strength each; green made up of 3 units of blue and 3 units of yellow; and gray of 2 units blue + 2 units yellow + 2 units red. The actual amounts of light of all colors reaching the eye would then have been equivalent. At least, however, the use of the Lovibond units at their face value gives three colors, red, yellow and blue, of equal brightness.

TABLE V

Color	Adaptation	Observer C			Observer K		
		Complementary	Contrast	Direction of Difference	Complementary	Contrast	Direction of Difference
R	N	$\frac{B}{G}=0.42$ (.03)	$\frac{B}{G}=1.12$ (.18)	bluer	$\frac{B}{G}=0.42$ (.04)	$\frac{B}{G}=0.51$ (.04)	bluer
	R	0.37 (.03)	1.27 (.25)	bluer	0.40 (.03)	0.76 (.36)	bluer
	Y	0.41 (.04)	1.05 (.31)	bluer	0.37 (.05)	0.68 (.38)	bluer
	G	0.41 (.04)	1.30 (.24)	bluer	0.43 (.04)	0.59 (.28)	bluer
	B	0.42 (.05)	1.24 (.17)	bluer	0.44 (.04)	0.64 (.35)	bluer
	A	0.41 (.03)	1.25 (.41)	bluer	0.38 (.06)	0.75 (.25)	bluer
Y	N	$\frac{R}{B}=0.23$ (.03)	$\frac{R}{B}=0.75$ (.24)	redder	$\frac{R}{B}=0.19$ (.03)	$\frac{R}{B}=0.66$ (.13)	redder
	R	0.21 (.04)	0.66 (.21)	redder	0.22 (.03)	0.76 (.28)	redder
	Y	0.17 (.03)	0.52 (.14)	redder	0.20 (.02)	0.86 (.18)	redder
	G	0.20 (.03)	0.60 (.11)	redder	0.25 (.02)	0.94 (.17)	redder
	B	0.23 (.04)	0.71 (.21)	redder	0.20 (.01)	0.74 (.09)	redder
	A	0.20 (.03)	0.60 (.20)	redder	0.21 (.03)	0.88 (.15)	redder
G	N	$\frac{B}{R}=0.46$ (.05)	$\frac{B}{R}=0.43$ (.10)	(redder)	$\frac{B}{R}=0.46$ (.05)	$\frac{B}{R}=0.37$ (.06)	redder
	R	0.42 (.05)	0.45 (.05)	(bluer)	0.43 (.04)	0.26 (.06)	redder
	Y	0.49 (.04)	0.54 (.11)	(bluer)	0.40 (.05)	0.27 (.10)	redder
	G	0.42 (.05)	0.51 (.12)	(bluer)	0.44 (.07)	0.25 (.06)	redder
	B	0.44 (.06)	0.46 (.07)	(bluer)	0.45 (.03)	0.40 (.10)	redder
	A	0.48 (.04)	0.44 (.07)	(redder)	0.43 (.07)	0.31 (.05)	redder
B	N	$\frac{R}{Y}=0.35$ (.04)	$\frac{R}{Y}=1.86$ (.18)	redder	$\frac{R}{Y}=0.30$ (.05)	$\frac{R}{Y}=1.64$ (.35)	redder
	R	0.31 (.05)	1.61 (.23)	redder	0.34 (.05)	1.81 (.10)	redder
	Y	0.27 (.05)	1.33 (.16)	redder	0.31 (.03)	1.61 (.14)	redder
	G	0.32 (.04)	1.60 (.09)	redder	0.38 (.04)	1.64 (.07)	redder
	B	0.36 (.05)	1.74 (.05)	redder	0.31 (.02)	1.78 (.14)	redder
	A	0.32 (.04)	1.27 (.02)	redder	0.31 (.06)	1.35 (.18)	redder

noticed that, while the two subjects agree rather closely in their determinations of both complementary and contrast colors of blue and of yellow, and of the complementaries of red and of green, they differ very much in regard to the contrast color of red, and somewhat in regard to the contrast of green, observer C. having a tendency to see more blue in the contrast than is seen by K. The same difference between the two observers is shown in Tables III and IV, though it is somewhat less strong there. K. also tends to see the contrast of yellow as a somewhat redder violet than does C. This difference is more marked in Tables III and IV than in Table V. The writers have no ex-

planation to offer for these differences between their observations, but can only call attention to three points: *First,* and most important for our particular problem, that the difference is one of *degree* of anomaly of the contrast color, merely, not of the direction of the anomaly. *Second,* that the judgments of the contrast color are much more difficult and much less certain subjectively than those of the complementary. The contrast ring takes on a peculiarly shimmering, transparent color which is extremely hard to match to the relatively dead, opaque color of the contrast disk. Accordingly, the individual determinations of the contrast colors show far wider variations than do those of the complementaries, as is shown by the mean variations. Some of the differences between the two observers, however, are very much too large to be accounted for on the ground of accidental variations due to the difficulties of judging the contrast color. *Third,* the differences between the subjects can hardly be due to differences in the selective absorption of the pigment of the eye, for, in the first place, both subjects have very dark brown eyes; and, in the second place, the differences between the observers come out in their determinations, not of the physically aroused complementary colors, but of the physiologically aroused contrast colors.

The negative results of the tests of this and the preceding group, in regard to the main point at issue, namely, the dependence of the direction of the anomaly on the conditions of color adaptation at the time of observation, at once suggests a comparison of our results with those of Tschermak. That experimenter found, it will be remembered, that complementary colors, and still more negative after-images, differ from true "opposite" colors by being more reddish or bluish. In other words, the difference found by Tschermak between complementary colors and negative after-images is the same as that shown in our tests between complementary and simultaneous contrast colors. Tschermak reports the anomaly to be reversed for both after-image and complementary colors of blue, but more for the former than the latter, when the eye is artificially adapted to yellowish green. That is, the anomaly is reversed both as regards the quality of complementary and of negative after-image, and as regards the

direction of the difference between the two. Tschermak, therefore, explains the normal anomaly (if one may use the expression) as due to the supposedly purplish adaptation of the eye in ordinary daylight. Tschermak's work has already been criticised.[25] Our experiments would seem to show:

1. In agreement with Tschermak's that the complementary color of a given hue is either more reddish or more bluish than its true "opposite," if the Hering colored papers be taken as rough representatives of the "opposite" colors. We made, of course, no attempt to determine the introspectively "opposite" colors.

2. That the simultaneous contrast color, like the negative after-image, is still more reddish or bluish. The difference between contrast and complementary is especially marked with the colors blue and yellow.

3. That, however, this difference between contrast and complementary is not reversed in direction nor significantly changed in amount under conditions of artificial adaptation to red, green, yellow, or blue. This is not a direct disagreement with Tschermak. If his results could be accepted, it would merely indicate that the simultaneous contrast color behaves differently than does the negative after-image.

4. In direct disagreement with Tschermak, these results show no dependence of the quality of the complementary color on conditions of artificial color adaptation. This is what would be expected if the orthodox laws of color mixture are correct.[26] For both observers, the values of the complementary colors obtained under the different adaptations show only small and obviously chance variations.

In connection with the negative results given as (3) and (4) above, it should be noted that the colored glasses used for artificial adaptation in the experiments of this group were very weak. The glasses used in the tests of Group III were stronger, but, as already stated, those experiments were faulty in many ways. Lack of time prevented any further tests with glasses of greater

[25] *Cf.*, above, pp. 9-10.
[26] *Cf.*, above, p. 9.

strength under the more exact conditions of the later experiments, and it is, of course, not impossible that such tests would yield new and (though this is hardly probable) radically different results. The writers can, therefore, merely record the fact that within the limits of these experimental conditions, there was found no trace of a dependence of the quality of either complementary or contrast color on the color to which the eye was adapted at the time of the observation.

So far, in the discussion of results, no mention has been made of the gray adaptation in comparison with normal daylight adaptation. It will be remembered[27] that the gray adaptation was included in order to have a neutral adaptation more nearly comparable in brightness with the different color adaptations used, than in ordinary daylight. In the tests of Group III, there seemed to be a slight indication that, in the case of the contrast color at least, the anomaly decreases somewhat with decrease in the brightness of the light to which the eye is adapted.[28] If this is the case the normal adaptation of these experiments should show the greatest anomaly, that is, the strongest tendency toward purple,[29] and the gray adaptation the least. This is true in only one case, that of the contrast color of blue for the subject C. Evidently, therefore, within the small limits of variation of these tests, differences in brightness adaptation do not cause an appreciable change in the quality of either complementary or of contrast colors. It must be remembered, however, that the differences of brightness in these experiments are slight, and the chance variations in results are relatively large, especially in the case of contrast colors, where the judgments are difficult and subjectively uncertain. It is quite possible, therefore, as Hering and Hess suppose, that brightness adaptation does cause a difference in the quality of complementary or of contrast colors, or of both, and that the differences between them would disappear under conditions of dark adaptation.

[27] *Cf.*, above, p. 27.

[28] *Cf.*, above, p. 26.

[29] The tendency toward purple will, of course, take the form of a tendency toward blue of the complementary and contrast colors of red, and toward red for those of blue and of yellow.

The main conclusion, therefore, from the tests of this and of the preceding group is that the difference previously noted between simultaneous contrast and complementary colors persists independently of variations in the color to which the eye is adapted at the time of observation. If these experiments are trustworthy, the adaptation hypothesis of Tschermak is evidently inadequate to explain the anomaly. The writers have, however, no other explanation to offer at the present time, and must leave their conclusions in this negative form.

§ 7. Experiments. Group V.

The tests of the first four groups include the main body of the material. These tests are, of course, subject to the criticism that the two principal observers were also the persons who planned the work and conducted the experiments, and it is, therefore, possible that, in spite of all precautions, they are subject to the expectation error. Accordingly, in order to check at least a part of these results, supplementary experiments were made with the four untrained observers, D., H., Ke., and M., who knew absolutely nothing of the problem or of the results previously obtained. These observers, as undergraduates, could give only a very limited time to the work, but in each case it was possible to make several (two to five) determinations of the complementary, the simultaneous contrast color, and also the negative after-image of the four primary colors, red, yellow, green, and blue. The method for determining the first two was essentially that used in the previous work; the only difference being that, instead of the four Hering papers, red, yellow, green, and blue, we used for our equations the necessary colors from the Milton-Bradley series of eighteen spectral hues.[30] For example, a black and white disk can be matched by the Milton-Bradley red mixed with the Milton-Bradley blue-green and green-blue. In this series of papers, then, the complementary of red lies between blue-green and green-blue—nearer the former than the latter, as determined by the amounts of each necessary

[30] *Cf.*, the method used by MacGregor and Dix, *University of Toronto Studies* vol. II., No. 3, pp. 23-27.

to make the equation. Similarly, the contrast induced by the red disk is found to be matched by a combination of black and white with blue-green and green-blue in a slightly different proportion. As in the previous work, the disks to be matched were set up on two color-mixers with a fixation-point midway between them. Eye-movement was, therefore, eliminated, and all other conditions were as already described for the experiments of Groups I to IV.

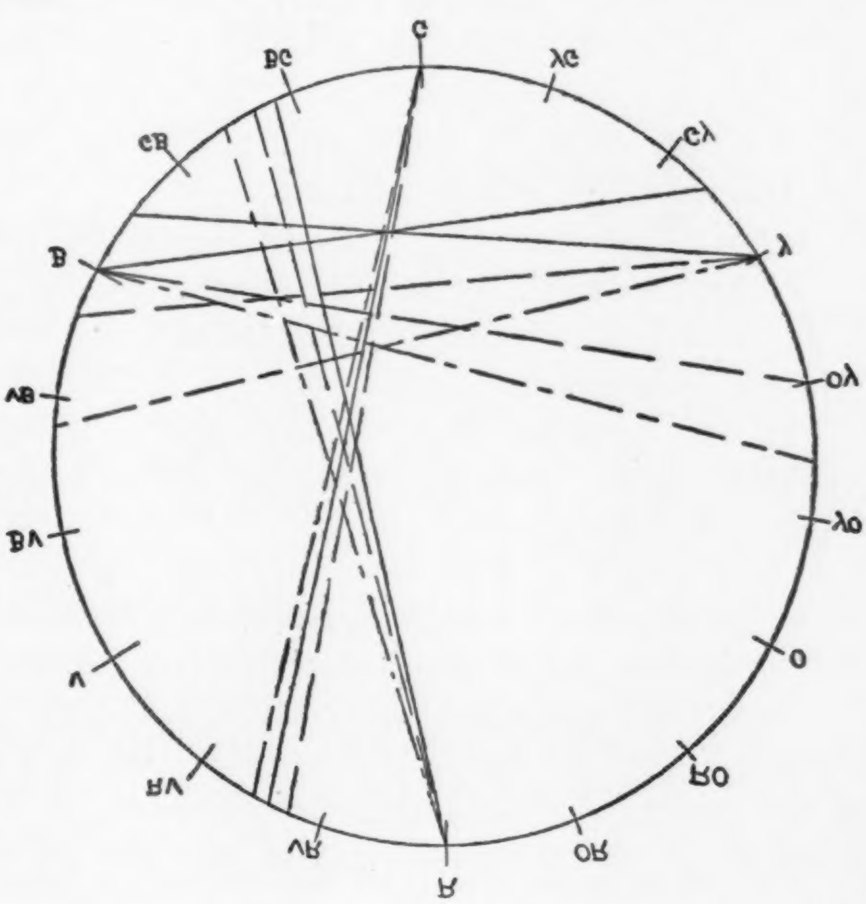
The quality of the negative after-image was determined roughly by the following simple method. On a neutral gray background were pasted two-inch squares of the eighteen Milton-Bradley hues in spectral order four inches apart. The two tints and two shades of each hue were placed at the same distance respectively above and below the hues. The completed chart thus gave a neutral gray background with colored squares equally distant from each other—horizontally, the eighteen Milton-Bradley hues in spectral order; vertically, five brightnesses for each color. One inch to the right of each square was marked a fixation point. The completed chart was hung in a north-west light across the same room used in the previous work.[31] On a second gray chart were pasted, some distance from each other, 2 inch squares of the four colors, red, yellow, green, and blue.[32] A fixation point was marked one inch to the left of each square. The observer obtained an after-image of a given color by fixating the point to the left of that color on this chart, and then the after-image was projected on the large chart on the neutral gray background between the colors. The observer's task was to determine which of the colors of this large chart most nearly matched the color of the after-image. For example, in one test,

[31] This chart was very bulky, as can easily be imagined. Two inch squares were used as the smallest size that would enable the observer to stand at a comfortable distance from the chart (1 yd. or a little over) and have about the same retinal area stimulated as in the determination of complementary and contrast colors (9.6 cm. seen at a distance of 2 meters). The ratio is only approximate, since the observer had to walk up and down in front of the chart, and it was impossible for her to keep at an exactly constant distance from it.

[32] These were put on the same chart solely for the sake of convenience. Only one color was used at a time.

subject Ke. decided that the quality of the after-image of red lay between blue-green tint 1, and green-blue, tint 1. Three fixation times were used for inducing the after-image: 30 sec., 1 min., and 2 min.; but, since no qualitative difference could be discovered in the results for the different periods of fixation, they will be treated together in discussing results. This method of determining the quality of the after-image is rough, but it has the advantages of consuming little time, and of being easy to use with untrained subjects, where very exact color matches cannot be expected.

The results can be given most clearly in graphic form, by arranging the eighteen colors around the circumference of a circle, and indicating by connecting lines the respective positions of the complementary, simultaneous contrast, and negative after-images of each of the four fundamental colors. The straight line (—) indicates the complementary, the broken line (— — —) the simultaneous contrast, and the dotted line (. . .)the negative after-image.



This circular chart gives the results obtained with the subject Ke. The results for the other three subjects, which were very similar to those for Ke., are as follows:

For observer D.—The complementary, simultaneous contrast color, and negative after-image of red are almost identical, all being approximately blue-green.

The same three values for the color green all lie very near together, between red-violet and violet-red.

For the color yellow, on the other hand, the complementary lies between blue and green-blue, the simultaneous contrast color is approximately blue, and the negative after-image lies between blue-violet and violet, nearer the former than the latter.

And for the color blue, the complementary lies between yellow and green-yellow; the contrast color between yellow and orange-yellow, but nearer the latter; and the negative after-image is approximately orange-yellow.

For observer H.—Color red: Complementary, between blue-green and green-blue, nearer the former; contrast, blue-green; after-image, between blue-green and green-blue, nearer the latter.

Color green: Complementary, between red-violet and violet, nearer the latter; contrast, violet-red; after-image, between violet-red and red-violet, nearer the former.

Color yellow: Complementary, between blue and green-blue, nearer the latter; contrast, between the same colors but nearer the former; after-image, between violet-blue and blue-violet.

Color blue: Complementary, midway between yellow and green-yellow; contrast, between orange-yellow and yellow-orange, much nearer the latter; after-image, between yellow-orange and orange, nearer the former.

For observer M.—Color red: Complementary, between blue-green and green-blue, nearer the former; contrast, midway between blue-green and green-blue; after-image, blue-green.

Color green: Complementary, between red-violet and violet-red; contrast, violet-red; after-image, red-violet.

Color yellow: Complementary, between blue and green-blue,

nearer the former; contrast, between blue and violet-blue, nearer the latter; after-image, midway between blue-violet and violet.

Color blue: Complementary, between yellow and green-yellow, somewhat nearer the former; contrast, between yellow and orange-yellow, nearer the latter; after-image, between yellow-orange and orange, nearer the latter.

It is evident from these results that the supplementary tests with untrained and unprejudiced subjects, using the Milton-Bradley series of colored papers instead of the Hering, show exactly the same anomaly of contrast and complementary colors in the cases of blue and of yellow as that discovered originally by Goethe and J. Müller, and brought out both by Tschermak and by the experimenters of the present series. Both the simultaneous contrast and the after-image colors of blue and of yellow are distinctly redder than their respective complementary colors. The difference is greater for all four subjects in the case of the negative after-image than in that of the simultaneous contrast color. The differences between complementary, contrast, and after-image colors of red and of green, on the other hand, are too small to be of significance with these few experiments on untrained observers. This negative result in regard to red, however, does not necessarily disagree with the fact that Tschermak found the after-image of red to be bluer than its complementary, and the tests of Groups I-IV in the present series brought out the same difference between the complementary and the simultaneous contrast colors of red. The apparent disagreement is almost certainly due merely to the fact that the anomaly in the case of red is too slight to be evident from the rough tests of this group. On the other hand, even in these tests, the anomaly for blue and for yellow is strikingly apparent, especially in the case of the after-image.

§ 8. Conclusions.

The writers realize very well that the experiments described in the preceding sections leave unanswered many more problems than they succeed in solving. Since, however, it is unlikely that either experimenter will be able to continue this line of work in

the near future, it has seemed worth while to report the results even in this unfinished state. In a word, it may be said that the tests are positive as regards the existence of a difference between complementary and contrast colors, both simultaneous and successive, but negative as regards any explanation of the difference. The main points in this conclusion may be summarized as follows:

1. There is a constant difference between complementary and simultaneous contrast colors of the three primaries, red, yellow, and blue. The contrast color of red is bluer than its complementary; the contrasts of yellow and of blue are redder than their respective complementaries. The contrast of green, on the contrary, is about the same as its complementary, showing slight (probably accidental) variations, sometimes toward red, again towards blue (Experiments, Groups I-V). The same anomaly is seen to a still greater degree in the case of the after-images of blue and of yellow, and probably to a slight degree in the case of red (Group V and experiments of Tschermak). This conclusion agrees with that of Tschermak that the contrast color differs from the complementary by tending toward purple.

2. The anomaly of the simultaneous contrast color remains constant in direction with variations in brightness contrast between contrast-inducing and contrast-suffering surfaces. Its amount is probably greatest when brightness contrast is eliminated (Groups I and II).

3. This anomaly does not depend upon after-images induced by eye-movement, since it persists both with foveal vision and free eye-movement, and with slightly extra-foveal vision and elimination of eye-movement (Groups I and II).

4. It is not altered in direction nor appreciably changed in amount by artificial adaptation of the eye to different colors, at least within the limits of color-adaptation used in these experiments (Groups III and IV). It can hardly depend, therefore, as Tschermak supposes the similar anomaly of the after-image to depend, on a purplish adaptation of the eye in ordinary daylight.

The work leaves unsolved the problems:

First, and foremost, of the explanation for the difference between the complementary and contrast colors, including the question of its dependence on the degree of brightness to which the eye is adapted at the time of observation.

Second, the question of the exact relation in quality between negative after-images and colors induced by simultaneous contrast, and the similarity or dissimilarity of their behavior under conditions of artificial color-adaptation.

And as secondary problems suggested during the course of the experiments, but not investigated further:

Third, do lighter surfaces suffer more color contrast effect than darker ones, under equal conditions of brightness contrast between contrast-inducing and contrast-suffering surfaces?

Fourth, to what extent are the amount and the quality of contrast effect influenced by the time of fixation; *i.e.,* what is the temporal rise of the simultaneous contrast color in amount and in quality?

Fifth, do individual observers differ, not only as regards the amount of simultaneous contrast effect which they see under given conditions, but also as regards its quality? If so, what is the explanation of the difference?

It remains only to reiterate that the chief incentive of the writers for reporting the work in its present state is the hope that these experiments, incomplete and rough as they are in many respects, may help the workers in some other laboratory to a solution of one or more of the problems suggested.

A Study of Spatial Associations in Learning And in Recall

BY

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INTRODUCTION

A STUDY OF SPATIAL ASSOCIATIONS IN LEARNING AND IN RECALL

Introduction

This study is a companion-piece to the paper by Jacobs on "Lernen mit äusserer Localization" published in the forty-fifth volume of the *Zeitschrift für Psychologie und Physiologie der Sinnesorgane.* The experiments of Jacobs were made under the direction of Professor Georg Elias Müller in the "psychologisches Institut" of the University of Göttingen a year or two before our own experiments were undertaken. Our experiments were begun in the same laboratory under the same guidance in the academic year 1906-1907 and were continued at Wellesley College in the year 1908-1909. It was in this year that the second writer took part in them and it was in the spring of this year that the experiments of Part I, were completed. The experiments of Part II, were made in the following year. Professor Müller inaugurated both the experiments of Jacobs and our own by serving as subject.

In his first sentence, Jacobs refers to the most common case of the "external localization" of remembered words. When we wish to find a given passage in a familiar book, we are apt to be guided by our recollections of the place where it stood—on the right-hand or on the left-hand page, toward the top or toward the bottom or about the middle. This external localization is distinguished by Jacobs from "internal localization." The external localization of verbal material is the association of words or syllables with objects or with spots in the subject's perceptual field of vision. Internal localization is the association of the words with points in the subject's imaginal or mental field. This inner field (we may infer) is constructed by the subject's imagination; it is not a memory-copy of any given perceptual field and the points at which one localizes the words do not correspond to any points at which they ever stood when one actually read them

from a book or paper. If in thinking of the fifty-third canto of *In Memoriam,* I visualize the four stanzas in their proper positions on the right-hand page of my Rolfe edition, this is not internal but is external localization. If, on the other hand, I wish to remember four five-figure telephone-numbers and choose to visualize them as written horizontally in parallel rows, one under another, this would be an instance of true internal localization. The problem of Jacobs was to investigate the advantage of voluntary internal localization in learning material presented to the ear and, therefore, not given in any spatial setting. In the major part of his experiments, nonsense syllables were employed. The series were learned by the method of complete memorizing and, in the later groups of experiments, the firmness of the associations was tested, after varying intervals, by the method of right associates. In half the experiments, the subject, when learning, was required to "localize" the syllables severally upon round black spots arranged in a simple scheme upon a sheet of white paper. In the other half, he was required to close his eyes but was left to his own devices with regard to internal localization, which was neither required nor forbidden. The experiments proved that learning with external localization had a slight but unmistakable advantage, both as regards the number of repetitions necessary for memorizing and as regards the number of right associates obtained after an interval. This showing is the more significant because, as a matter of fact, nearly all the subjects, whether visualizers or not, did actually, when learning with closed eyes, project more or less complete visual images of the syllables into the internal field of vision in a pattern more or less resembling the external localization scheme. Incidentally, Jacobs showed that external localization is rendered difficult by a rapid rate of presentation and that it is of doubtful advantage in learning material with meaning, such as stanzas of poetry.

The first and most important part of our own experiments, the part begun in Göttingen, is in contrast, and at the same time complementary to the experiments of Jacobs in the following points: In the first place, the material—which consisted of "normal" series of nonsense syllables—was presented to the eye

and, moreover, was presented in such a manner as to foster to the utmost memories of spatial positions and relations. The subjects were not, indeed, instructed to indulge in external localization but they read the syllables from the sharply demarcated and symmetrically arranged fields of an exposure-tablet and could not well avoid forming place associations. In the second place, we used the method of right associates, pure and simple. Thus, none of our series were supposed to be completely memorized.[1] Our purpose was not directly to test the value of external localization in memorizing,—as Jacobs tested it in terms of neces-

[1] A brief description of this method may be convenient to some readers. The method of right associates is the *Treffer- und Zeitmethode* of Müller and Pilzecker. (*Experimentelle Beiträge zur Lehre vom Gedächtniss,* Zeitschrift für Psych. und Physiol. der Sinnesorgane, Ergänzungsbund I, pp. 3-24.) In this method, series of impressions—say, of nonsense syllables—are presented to the subject a number of times, which should always be insufficient for complete memorizing. After an interval long enough to allow all mental echoes of the series to die away,—an interval perhaps of three minutes, perhaps of twenty-four hours—half the syllables, either all the odd-number syllables or all the even-number syllables, are presented to the subject singly and never in the order in which they originally stood. The subject is required to name in each case the next succeeding or the next preceding syllable according to the half of the syllables selected for presentation. The reproduction time, or the time during which the subject reflects before he responds with "Nichts" or "Don't know," is measured. The results are in terms of four classes of cases, right cases, wrong cases, partly right cases, and zero cases, with the corresponding average reaction times. Cases in which the subject names exactly the syllables which he is required to name are, of course, right cases. Cases in which he names a syllable which has two elements in common with the proper syllable or which contains the proper elements in reverse order are partly right cases. (The three elements of the Müller syllables are the initial consonant, the central vowel or diphthong, and the terminal consonant.) All other cases in which syllables are named are counted as wrong cases. Cases in which the subject names no syllable at all make up the class of zero cases. In the case of a positive reaction, the time actually measured is always slightly greater than the reproduction time proper since it contains not merely this time but also the time necessary for the subject to apprehend the syllable presented, his motor reaction time, and the negligible time spent in overcoming the inertia of the apparatus. The reproduction time is, however, not merely the largest but also the most variable part of this gross reaction time, so that we may safely assume that when the gross reaction time is short, the association is strong and unimpeded, and that when the gross reaction time is long, the association is weak or partially inhibited.

sary repetitions,—but to test it indirectly by gauging, as we shall explain in a moment, the importance of place associations in recall. In the third place, the stimulus-syllables in our test-procedure were exposed under two different conditions. We exposed part of them in the same positions on the exposure-tablet in which they had stood when the subject read the series and we exposed the rest in other places. By this procedure, we sought to determine whether or not syllables exposed in "right" places were more likely to evoke the proper associates than syllables exposed in "wrong" places. If this is a fact, it is an indirect proof of the importance of place associations in learning, for in the cases of right exposure, the place associations would seem to reinforce the associations between the pairs of syllables. Moreover, if syllables presented in the wrong places are relatively unlikely to recall right associates, or if the reproduction time is unduly prolonged, one may well suspect an interference between two sets of associative connections. Suppose, for example, that a test-procedure is in progress in which the subject is required to name the syllable following the syllable exposed. Suppose, further, that the syllable which stood in the third place when the subject read and reread the series is now exposed in the seventh place. This seventh place will suggest the eighth place and this place in turn will tend to suggest the syllable which stood in the eighth place. On the other hand, the third syllable itself will not only tend to suggest the fourth syllable but will also suggest the third place. The third place will suggest the fourth place and this place in turn will also tend to suggest the fourth syllable. If both sets of associations are strong, some blocking of the reaction will be almost inevitable.

As a matter of fact, the numerical results do show a clear though slight correlation between right exposure and right response and between wrong exposure and incorrect or negative response. They also show a correlation between correct recall of the place in which a stimulus-syllable originally stood and reaction with the proper syllable. This last fact, however, is no proof of the instrumentality of place associations in the recall of

the right syllable, since the syllables were learned undoubtedly in and with their spatial settings on the tablet, and it must have been perfectly possible to recall both the place of the stimulus-syllable and the syllable paired with it without having the one memory dependent upon the other. Nevertheless, the introspection of the subjects shows conclusively that place associations did play an important part in the recall of syllables.

The second and less important part of our experiments is supplementary both to the first part and to the experiments of Jacobs. In these experiments, also, we presented normal series of nonsense syllables to the eye and employed the unmodified method of right associates. But whereas in the first part of the experiments all the series were learned from the exposure-tablet, in the second part half the series were learned from a revolving drum. Moreover, during the test-procedure in these latter experiments, all the syllables out of all the series were exposed in the same place upon the tablet, whereas in the earlier experiments they were shown in different places. Thus in half the experiments of this second part, spatial associations were fostered by the use of the exposure-tablet in memorizing, and in the other half, they were minimized by showing the syllables singly in a screen-slit in front of the drum. In the drum series, however, the subjects were left at perfect liberty to have an exposure-tablet in the mental field of vision. Consequently, these experiments are exactly parallel to those of Jacobs, with the substitution of visual for aural presentation and of the method of right associates for Jacobs's combination of this method with the method of complete memorizing. In other words, we strove to determine the value of place associations in memorizing by testing the *degree* to which the two sets of series were mastered with the same number of repetitions, whereas Jacobs sought primarily to find the number of repetitions necessary for *completely* memorizing his two sets, testing incidentally the firmness of the once-perfected associations by the method of right associates. Some of our work miscarried and the results which are worth reporting are not extensive but, as far as they go, they are in entire harmony both

with the results of Jacobs and with the data obtained in our own earlier experiments.[2]

[2] In his opening pages, Jacobs summarizes earlier and incidental observations in regard to the rôle of place associations in memorizing. One of the most important of these observations is that of Müller and Pilzecker (*op. cit.*, p. 221) to the effect that associations of "absolute place" in memorizing syllables, visually presented, may take at least three forms, *viz.:* associations between the several syllables and number words (such as *third* or *eighth*), associations between syllables and the intonations with which the subject may read aloud various parts of the series, and associations between syllables and some visible marker of spatial position (such as the strip of blank paper separating the last from the first syllable upon the exposure-drum). All these associations may properly be called place associations, but only the last class are spatial. Our own experiments and those of Jacobs were entirely concerned with associations of spatial place and the term *place associations* must here be understood to refer exclusively to associations of spatial position.

Although Professor Müller suggested and planned the experiments here reported, the interest of the first writer in spatial associations did not begin in Göttingen but in memorizing blindfold, at Wellesley, series of smells by the reconstruction method. In these experiments, the subject made use not merely of visual images of parts of the table and of her own body but also of percepts and images of the arm-movements involved in placing the scent-bottles at various points on the table. The writer attributes her success in memorizing and reconstructing the series largely to the precision of her place memories. See *Memorizing Various Materials by the Reconstruction Method, Wellesley College Studies in Psychology, Number 1,* Psych. Review, Whole Number 43, pp. 9, 106-107, 116 and 127.

PART I

SPATIAL ASSOCIATIONS IN RECALL

Method, Material and Apparatus

We have already stated that our experimental procedure was the method of right associates (*Treffer- und Zeitmethode*) of Müller and Pilzecker. In the following paragraphs, the peculiar features of our own procedure will be noted, the apparatus employed will be described and the nature of the nonsense syllables memorized will be exactly specified.

I. *Peculiarities of Our Own Method.*—The topics which should receive mention in a description of our own method are these: (*a*) presentation of material, (*b*) rate and rhythm of repetition, (*c*) number of repetitions, (*d*) the conduct of the test-procedure, (*e*) the statistical treatment of results and (*f*) the requirements made of the subjects.

a. Presentation of Material.—In our own experiments, as we have already noted, presentation was visual and the syllables were read, in time with a metronome, from the sharply demarcated sections of an exposure-tablet. This method of presentation was adopted because, as we have already said, the point at issue in these experiments was the assistance in recall which might be rendered by spatial associations formed during the process of memorizing. The exposure of the syllables in the "squares" of the exposure-tablet made the formation of such associations easy and almost inevitable. The subject read the series line by line from left to right, looking at the tablet through the slit in the fall-screen which will presently be described. The experimenter could govern the time during which the series was visible by opening and closing the slit.

b. Rate and Rhythm of Repetition.—In all our experiments the series were read in strong trochaic rhythm. The rate of repetition for all the American subjects except G. was one syllable

to a second and for the subjects M. and G. one syllable to every five-sixths of a second. The untrained American subjects were allowed to read at the comparatively slow rate of one syllable to a second because the irregularities of spelling and pronunciation in the English language make relatively difficult the pronunciation of nonsense syllables presented to the eye as well as the spelling of nonsense syllables presented to the ear.

c. Number of Repetitions.—The number of repetitions was varied from subject to subject since, in the method of right associates, the number should never be so great as to enable the subject to give more than 50 per cent on the average of right answers in the test-procedure. The number was usually diminished for the individual subject as practice increased. The number of repetitions allowed to each subject is given in Table I.

d. The Test-Procedure.—The points which should be noted are: (1) the interval between the learning and the testing of each series, (2) the choice of syllables for presentation, (3) the order in which these syllables were exposed, and (4) the system according to which the syllables were shifted from the positions in which they stood when the series were learned.

1. In all our experiments the interval allowed to elapse between the last presentation and the testing of the subject's mastery of the series was three minutes. During this interval, the subject's attention was distracted; M. read the *Fliegende Blätter;* the other subjects were "entertained" by the experimenters.

2. All our subjects except G. and W. were shown odd-number syllables and were required in each case to name the syllable following. Regressive recall was required of G. and W. because Professor Müller, after serving as subject with progressive recall, suggested that regressive recall would put a higher premium upon spatial associations. Regressive recall was not required of the unpractised subjects, B., D., H., and P. because the task was supposed to be too difficult for them.

3. It is necessary to present the syllables which are to evoke reactions, in an order different from that in which they stood in the original series. If the order is the same, the method virtually

becomes a variety of the prompting method and the process of recall is akin to continuous recitation. Moreover, the syllables which occupy the same numerical positions in the series should not be presented in the same order from day to day,—*e.g.*, the order of presentation should not always be 11, 7, 3, 9, 5, 1,—because the last syllable presented always has a special advantage and a special disadvantage which may or may not compensate. On the one hand, the subject can often arrive at the proper reaction by a process of elimination, by guessing at the right syllable from the syllables he has already named and, on the other hand, the association to be tested is least fresh, being separated by the widest interval of time from the learning process. Therefore, a compensating program of exposures should always be adopted. The program employed in our experiments with series of twelve syllables was copied from the procedure of Müller and Pilzecker and was as follows: Series 1, Syllables 11, 7, 3, 9, 5, 1; Series 2, Syllables 7, 3, 9, 5, 1, 11; Series 3, Syllables 3, 9, 5, 1, 11, 7; Series 4, Syllables 9, 5, 1, 11, 7, 3. And so on in a cycle. The program used with series of eighteen syllables was exactly similar except in the case of the too expert subject G., for whom a special program (unknown to herself), had to be made out. In this case the initial order was 18, 12, 6, 16, 10, 4, 14, 8, 2. This order was, of course, also treated in cyclic fashion.

4. We have already stressed the point that in our experiments it was essential that the syllables should be presented to the eye in different places upon the exposure-tablet, sometimes in the position in which they had been learned and sometimes in new or "wrong" positions. The shifts were made systematically by a compensating program. The places in which syllables had stood during the learning process were called "right places" and all new positions were called "wrong places." No syllable was ever shown directly above or below the right place. As a specimen procedure, part of the program used in the case of M. may be given. This subject learned three series a day. Each series contained eighteen syllables, so that nine syllables were presented in each test-procedure. Of these, either six or three were in wrong places—if six, the series was called "hard"; if three, it

was called "easy." The subject learned either two hard and one easy series a day or *vice versa,* according to an alternating program. On the first day of the experiments actually taken into account, the shifts in the first series were as follows: 1st syllable to 3rd place, 3rd to 5th, 5th to 1st; and 7th syllable to 9th place, 9th to 11th, 11th to 7th. In the second series, they were: 13th to 15th, 15th to 17th, and 17th to 13th. In the third series, 1st to 9th, 9th to 17th, 17th to 1st; and 3rd to 11th, 11th to 13th, 13th to 3rd. On the second day, the shifts were as follows: 1st series, 5th to 7th, 7th to 15th, 15th to 5th; 2nd series, 5th to 9th, 9th to 13th, 13th to 5th, and 3rd to 7th, 7th to 17th, 17th to 3rd; 3rd series, 1st to 11th, 11th to 15th, 15th to 1st. Third day: 1st series, 13th to 11th, 11th to 3rd, 3rd to 13th, and 15th to 7th, 7th to 5th, 5th to 15th; 2nd series, 17th to 9th, 9th to 1st, 1st to 17th; 3rd series, 17th to 7th, 7th to 3rd, 3rd to 17th and 15th to 11th, 11th to 1st, 1st to 15th. Fourth day: 1st series, 13th to 9th, 9th to 5th, 5th to 13th; 2nd series, 11th to 9th, 9th to 7th, 7th to 11th, and 17th to 15th, 15th to 13th, 13th to 17th; 3rd series, 5th to 3rd, 3rd to 1st, 1st to 5th. The program continues in a cyclic series of variations which need not encumber these pages. The cycle of shifts was completed in two more days. This cycle was repeated three times and was once more about half completed. The experiments taken into account extended over twenty days.

e. *Statistical Treatment of Reactions.*—A few words should be said on this point because our sets or "constellations" of cases are not grouped in the ordinary fashion of the method of right associates. Usually the sets are grouped according to the conditions under which the different *series* were learned. In our experiments the sets are formed according to the conditions under which the different *syllables* were presented in the test-procedure. Thus, syllable-reactions belonging to the same series may be included in different sets of cases and syllable-reactions belonging to different series may be included in the same set of cases.

f. Requirements Made of the Subjects.—As we have already said, the subjects were required to read the series aloud in tro-

chaic rhythm to the beats of a metronome. They were told to begin reading the series on the second beat after that upon which it was exposed, and at the end of each repetition to allow two beats to pass before beginning the next. They were not especially enjoined to memorize without the use of auxiliary associations (mnemonic devices). The experimenters believed that the prohibition of such devices does not really inhibit their use even in the case of conscientious subjects, and hoped that a profuse crop of auxiliary associations would be prevented by the rather rapid rate of reading. As will later appear, they were in some degree disappointed in this expectation but they were far from "encouraging" the subjects to make such associations. Special instructions had to be given to the subjects in regard to the use of the lip-key but these instructions need scarcely be repeated here. After each reaction, the subject was asked whether the syllable exposed had been shown in the right place. If he answered "No," he was asked to name the place where it really had stood in the process of learning. He was allowed to answer this question either by giving the number of the rhythmical foot or by saying "the first place," "the ninth place" or the like, or by saying "the second place in the second row" or the like. After the final testing of each series, he was also supposed to state any auxiliary associations which might have come into play. The attention which was thus called to mnemonic devices probably had the unfortunate effect of increasing their number. Lastly, in zero cases (cases in which the stimulus-syllable recalled no other syllable at all), the subject was asked (after each reaction) whether the syllable exposed seemed familiar (*bekannt*) or unfamiliar (*fremd*).

II. *Apparatus.*—The apparatus may be described under two headings: (*a*) the exposure-tablet and (*b*) the apparatus used in measuring reaction time. Under (*b*) the actual manipulation of the apparatus used in the time measurements will also be described.

a. Exposure-Tablet.—This was designed by Professor Müller for these experiments.[3] As used in the Wellesley experi-

[3] The tablet was made by Spindler and Hoyer of Göttingen. See their *Apparate für psychologische Untersuchungen, Preisliste* 21 (1908), p. 157.

ments, it consisted of a metal frame which was supported by two metal uprights upon a wooden base. The frame itself was composed of four sections, each about 38 cm. long and each containing six rectangular openings, 3.8 by 3.2 cm. in size, with the long side horizontal. When the sections were fitted together, the twenty-four openings were separated from one another by narrow margins of metal and formed a very compact field, so that no sweeping eye-movement was required in passing from the right end of one row to the left end of the row below. The field of openings was bordered above, below, and on both sides by a wide margin of the metal. Each of the four plates had a back with a spring-hinge, opening downwards and divided into six compartments into which cards could easily be slipped. When this spring-back was in position, the cards filled the open spaces in the upright part of the metal plate. The whole framework was painted black so that the white cards, upon which the syllables were written, were sharply defined by their borders and had somewhat the effect of four horizontal rows of lighted windows upon a blank and dark wall. The metal plates were supplied at each end of the back with rings which slid up and down upon the uprights of the base. Thus, two, three or four plates could be used at one time according to the length of the series. (Two of the plates were supplied with a wide margin of metal upon one of their horizontal edges.) The level of the field could be slightly altered to suit the convenience of subjects of different heights. The subjects sat at the end of a table with the fall-screen, presently to be described, between them and the tablet. Both the level of the tablet as a whole and its distance from the screen were altered to suit the eye-level and reading-distance of the different subjects. To the end of the table was clamped an adjustable chin-rest modelled after the one in use in the Göttingen laboratory. This description of the exposure-tablet applies in detail only to the one used in the experiments made in the Wellesley laboratory in the years 1908-1909 and 1909-1910. The tablet used in the Göttingen experiments in 1906-1907 was the first of its kind and was inferior to the tablet just described. Upon this tablet, only eighteen syllables could be

presented and the openings were much larger, so that the eye-movements involved in glancing from one part of the field to another were considerable.

b. Apparatus Used in Measuring the Reaction Time.—Throughout our experiments, this apparatus was almost exactly similar to that used by Müller and Pilzecker, and described in detail by these writers.[4] In fact, the fall-screen and lip-key used in the first group of experiments (those made in Göttingen) were the very same screen and key which Müller and Pilzecker had employed. The apparatus used in the Wellesley experiments will be described in some detail, since it differed in a few particulars from that of Müller and Pilzecker, and since the reader may not have the work of these investigators freshly in mind. The apparatus included two electric circuits. In the first, we had a storage battery of about ten volts, a commutator, a simple homemade arrangement for introducing variable resistance, and the electromagnet of the fall-screen. This fall-screen really consisted of two screens, a fixed screen, 75 cm. high and 45 cm. wide, made up of a wooden frame painted black and filled in at the front with black card-board, and a movable screen of the same material which slid up and down in a groove behind the card-board front of the larger screen. Both screens contained slits, 18 cm. from side to side and 5 cm. from top to bottom. When the electric circuit was closed, the current flowed through the coils of an electromagnet at the top of the fixed screen and the fall-screen was held suspended by means of the armature on its top. When the fall-screen was in this position the slit in the fixed screen was covered. At the instant the circuit was broken, the movable screen fell and came to rest in such a position that the slits in the two screens coincided. It was behind this opening that the exposure-tablet was placed In the second circuit, we had a storage battery of two volts, a commutator, a resistance device similar to the one used in the first circuit, a Hipp chronoscope, its control apparatus, the lip-key, and a make-and-break device attached to the side of the fixed

[4] Pp. 3-7. The lip-key used at Wellesley was made by Spindler and Hoyer and is described on page 128 of *Preisliste 21*.

screen. The lip-key and make-and-break device were in parallel. The make-and-break device consisted of a small metal lever which, as long as the movable screen was held up, lay across two binding posts on the frame of the fixed screen. When the fall-screen came down, it struck that end of the lever which did not lie across the posts and came to rest upon it, thus raising the other end and keeping the circuit open at this point. This chronoscope circuit could also be made and broken at the lip-key. The connections were so adjusted that the chronoscope ran on the open circuit. The chronoscope-control instrument in the Wellesley experiments was the Ebbinghaus fall-apparatus. The lip-key was held at any desired height by clamps and rods attached to the subject's chin-rest.

Manipulation of the Apparatus.—In the Göttingen experiments all the work was done by one experimenter, but in the Wellesley experiments the same work was divided between two and sometimes between three persons. When in experiments by the method of right associates the interval between learning and testing (as in our experiments) amounts to only a few minutes, it is important that the testing should proceed as rapidly as possible for, if it drags, the first associations called into play will be much fresher than the last. At the beginning of the test-procedure and between the experiments with the different syllables exposed, both circuits were closed and the slit in the fixed screen was covered by the movable screen. As the first step in each test, an experimenter started the clock-work of the chronoscope. Its buzzing sound warned the subject to raise the lever of the lip-key, thus breaking the chronoscope circuit in the lip-key branch. The next steps were to bring the subject into an attitude of expectancy with the word "Los" or "Now", and about two seconds afterwards to break the magnet circuit at the commutator, thus allowing the movable screen to fall. As soon as the subject reacted, thus closing the chronoscope circuit through the lip-key branch, one experimenter lifted the screen into place and put upon the exposure-tablet the syllable next to be shown, while the other experimenter took the chronoscope reading and recorded the subject's reaction and introspection.

III. *Material.*—In the Göttingen experiments, the material memorized consisted of "normal" series of nonsense syllables made according to the Müller and Schumann rules as adapted by Müller and Pilzecker to series of eighteen members.[5] For the Wellesley experiments comparable series of twelve and eighteen members were made by adapting the Müller, Schumann and Pilzecker rules to the peculiarities of the English language. The rules applied in making these "English" series are given elsewhere in great detail by the first writer.[6] A typical series of eighteen members is the following: *buv, chure, seje, poit, yed, zobe, thas, life, wouz, kane, tish, vox, make, goig, fith, huch, jam, rel.* These series are to be pronounced strictly "by sound,"—*i.e.*, according to the sounds proper to the English letters in the several combinations. Thus, *buv* should rhyme with *dove, chure* with *sure, poit* with *quoit, yed* with *red,* and *zobe* with *robe,* and *seje* should be pronounced like *siege.* When in our laboratory, such series are presented to the eye and read aloud by the subject, mistakes of pronunciation are promptly corrected by the experimenter.

Before we pass to the consideration of the experimental results, we must name the subjects who will figure in them. A description of the subjects as memorizers will be given in connection with the introspective data. The subjects who will be called M., G. and W. are, respectively, Professor Müller, and the two writers of this report. W. was, at the time these experiments were made, an undergraduate pursuing advanced courses both in psychology and in physics. She also served as experimenter upon other subjects and was chief manager of the apparatus. The subjects called B., D., H., and P. were Misses Helen Burr, Harriet Decker, Grace Hendrie and Hortense Peters. These four subjects were draughted in the spring term from a class of

[5] See Müller and Schumann, *Experimentelle Beiträge zur Untersuchung des Gedächtnisses,* Zeitschrift, f. Psych. und Physiol. der Sinnesorgane, 6, pp. 99-106; and Müller and Pilzecker, *op. cit.,* p. 3.

[6] See the study of *Memorizing by the Reconstruction Method* already cited, pp. 19-22. For additional discussion of these series, see p. 110 of these studies.

students who were completing a first but "three-hours-for-a-year" course in psychology.

Details in regard to the amount of work required of the several subjects are as follows: All the subjects worked through a short series of preliminary experiments, made to determine the proper number of readings, the best reading-distance, and so on. With B., D., H., and P., this preliminary series was very short, since the time which they could give to the experiments was strictly limited. In the experiments whose results are here reported, M. worked (as has been said) twenty days, learning three series a day; G., twenty-four days, learning four series a day; W., twenty days, learning three series a day; and B., D., H., and P., thirteen, fifteen, fourteen and sixteen days respectively, learning four series a day. The subjects worked about four times a week in successive weeks. With all except W., the interval between the end of a test-procedure and the first reading of the next series learned on the same day was about two minutes; with W., it was about five minutes.

The reader will easily see in following the discussion of results that they do not furnish data for exactly comparing the facility of the various subjects in memorizing. The conditions imposed upon the several subjects differed much. M., G., and W. learned series of eighteen members; the others, series of only twelve. M. and G. read at a rate faster than that of the untrained subjects and both had trouble in the mere "seeing" of the syllables, whereas all the others had younger and better eyes. M. G. and P. were allowed a much smaller number of readings than the others. Finally, G. and W. were assigned the task of naming the syllable preceding the stimulus-syllable, whereas all the others had the easier task of naming the syllable following. In particular, W. must not be directly compared with the other untrained subjects, since her longer series and the regressive recall demanded of her put her on quite another footing in spite of the large number of readings permitted her. This remark is made because in the pages which follow it is repeatedly necessary to call attention to the small percentage of right associates obtained by W.

Numerical Results

The numerical results furnish data for answering four main questions. (I) Is there a correlation between right and wrong exposure, on the one hand, and the percentages of right, partly-right, and wrong associates and zero cases on the other hand? This question bears upon the effect of an external condition (entirely within the control of the experimenter) upon the subject's ability to recall the proper syllables in the test-procedure of the method of right associates. To this question the effect of right and wrong exposure upon the reaction time in subsidiary. (II) Did the subjects actually remember the places in which the syllables exposed in the test-procedure had stood during the reading of the series? If so, were the subjects more likely to remember the place in which the syllable presented had stood or to recall the syllable which had been paired with it during the learning process? (III) Was right localization of the syllables presented a concomitant of right association? Was wrong localization a concomitant of wrong association? And was failure to localize a concomitant of failure to recall any associate? (IV) Was right localization a concomitant of the feeling that the syllable was familiar and ought to evoke the right associate? These last three questions are concerned, not with the experimenter's exposure of the syllables, but with the subject's localization of them. This was, of course, quite beyond the control of the experimenter, for although she could at will put the syllable presented into a right or into a wrong place on the exposure-tablet, she could in no wise insure the subject's remembrance of the original spatial setting of the syllable.

I. *Were the syllables which were, in the test-procedure, exposed in the places in which they stood when the series was memorized more likely to call up the proper associates than syllables exposed in places in which they had not stood? In other words, did wrong exposure conduce toward wrong or failing association?*

Table I shows the connection between right and wrong exposure and right, wrong and missing associates. In this table,

TABLE I

To Show the Relation of Right and Wrong Exposure to Right, Wrong and Missing Association

Subject	Series Length	Repetitions	Syllables Exposed		No. of Stimulus Syls.	Right Associates		Partly Right Asso.		Wrong Associates		Zero Cases	
			Numbers	Places		%	Time	%	Time	%	Time	%	Time
1	2	3	4	5	6	7	8	9	10	11	12	13	14
M.	18	6, 4	O.	*RS*	275	55	3110σ	3	9250σ	13	15800σ	28	15900σ
				FS	277	46	3430	6	9200	16	14520	33	14030
G.	18	4, 3	E.	*RS*	424	73	3550	4	4620	3	9600	20	10490
				FS	420	70	3360	3	7530	5	8390	22	10710
W.	18	12	E.	*RS*	274	39	2350	6	2860	7	4480	48	4080
				FS	258	37	2120	5	3190	7	4560	51	4100
B.	12	8	O.	*RS*	167	30	2520	8	3240	31	4070	31	4290
				FS	170	29	2430	7	3200	29	5160	35	4070
D.	12	8, 6	O.	*RS*	163	45	2550	6	3570	17	6800	33	8910
				FS	162	42	2740	6	4750	24	6700	29	9050
H.	12	8	O.	*RS*	150	51	2800	3	2990	10	7970	36	8840
				FS	150	49	3820	5	6430	7	9900	38	8400
P.	12	6, 4, 3	O.	*RS*	177	59	2740	4	6270	8	4810	29	7600
				FS	176	61	3610	4	3590	6	8950	30	9560

the columns are numbered from left to right for convenience of reference. In Column 4, the letters *O* and *E* stand for the words *odd* and *even* and mean that the syllables presented in the test-procedure—the "stimulus-syllables"—were, for a given subject, the odd-number or even-number syllables of the series. In Column 6, the letters *RS* and *FS* stand for the words *right settings* and *false settings* or for *richtige Stellen* and *falsche Stellen,* and refer to the right-place or wrong-place exposure of the stimulus-syllables.[7] Throughout the table, the average numbers of σ have been rounded out to the nearest multiple of ten. On this principle, 3104 would be called 3100 and 3106 would be called 3110. Numbers ending in 5 have been arbitrarily rounded out to the next *higher* multiple of ten.

The first cross-line of the table may be translated into words as follows: The subject Müller read over series of eighteen nonsense syllables at first six times but later four times. The syllables presented in the test-procedure were odd-number syllables. (Thus, this subject was required to name the even-number or succeeding syllables.) In all 275 syllables were shown in the right settings or places. Of these 275, 55 per cent called up right associates in an average time of 3110σ; 3 per cent called up partly right associates in an average time of 9250σ; 13 per cent called up wrong associates in an average time of 15,800σ; and 28 per cent called up no associates at all, although the subject reflected for 15,900σ—*i.e.,* for nearly 16 seconds—on the average.[8]

[7] *RS* and *FS* should perhaps be replaced in an English report by *RP* and *WP,* but the change would be confusing to the writers who have used the words *rictige Stellen* and *falsche Stellen* from the beginning of the work.

[8] Two points of detail in regard to Table I are these: (1) The numbers of *RS* (rightly exposed) syllables and of *FS* (wrongly exposed) syllables differ slightly in the case of every subject but one, because some syllable exposures had to be thrown out entirely for one reason or another. (2) Not all the *RS* and *FS* cases covered by the percentages in the tables actually have corresponding reaction times, but the difference between the total number of reactions counted and the number timed is negligible. In M.'s case, two reaction times are missing (were not secured or had to be thrown out) under the right associates for the *RS* syllables. The percentage given, 55, represents 151 cases, whereas only 149 were timed, giving the average of

The numerical results represented in Table I fall under two headings: (*a*) percentages and (*b*) average reaction times. The two classes of results will be discussed in order.

a. The percentages of right associates, zero cases, wrong associates, and partly right associates exhibit the following facts:

1. For all the subjects except P. the percentage of right associates (Col. 7) is at least slightly greater for the *RS* (rightly exposed, syllables than for the *FS* (wrongly exposed) syllables. The difference is greatest in the case of M. where it amounts to 9 per cent.

2. For all the subjects except D. the percentage of zero cases (Col. 13) is slightly greater for the *FS* syllables than for the *RS* syllables.

3. For some subjects the percentage of wrong associates (Col. 11) is greater for the *FS* syllables and for other subjects it is greater for the *RS* syllables. Only in the case of D. is the difference considerable. A moment ago it was noted that this subject alone had a larger percentage of zero cases for the *RS* than for the *FS* syllables. Her percentages of wrong cases show a compensating difference, and, if we add together her percentages of wrong and zero cases (see Cols. 11 and 13), we shall find the sum rather greater for the *FS* than for the *RS* cases—53 per cent as against 50 per cent.

4. In no case are the percentages of partly right associates (Col. 9) large enough to merit serious consideration.

5. G.'s percentages of right associates are larger than they should be by the rules of the method. Her number of repetitions should certainly have been reduced to two. The percentages, however, are not too large to allow a difference between the *RS* syllables and the *FS* syllables to appear. Incidentally, it may be

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3110σ, which appears in col. 9. Two reaction times are missing under the wrong associates and three under the zero cases. That is, out of the 275 *RS* syllables counted in the table, seven lack proper reaction times. These figures are typical, and since the differences between the numbers of cases counted in the percentage columns and the numbers counted in the time columns are so very small, they can scarcely be allowed to encumber a table which is already complicated enough. The writers have in their own hands fine-spun numerical data upon this and all similar points.

remarked that M., B., and D. differ from the other subjects in having comparatively large percentages of wrong associates (Col. 11). W., who has many zero cases, has very few wrong associates; G. has few of either; and H. and P. are intermediates between G. and W.

b. In interpreting association-reaction times the following facts should be kept in mind: (1) A large percentage of right associates given in a short average reaction time means that the associations were strong and unimpeded. (2) A large percentage of right cases or a small percentage of zero cases coupled with a long average reaction time denotes a pertinacity on the part of the subject which has given many weak associations sufficient time to function. The high percentage of right associates may be interpreted as meaning a strong set of associations provided that a considerable number of the times which enter into the average are very short. (3) A small percentage of right associates or a large percentage of zero cases combined with a long reaction time means that the associations were either weak or impeded. (4) A small percentage of right associates or a large percentage of zero cases with a short reaction time means that only the strongest of the associations have had a chance to function, or, in other words, that the subject, frightened, self-conscious, indifferent, of hasty mental habit or what not, has taken little time to reflect. (5) A small percentage of zero cases with a short reaction time suggests that out of the set of associations tested a large number have been strong enough to function quickly but that the weaker have missed their chance to function because the subject, if he could not recall the right syllable on the instant, at once gave up the attempt. It need scarcely be said that the wrong-association times are to be interpreted in much the same way as the zero-case times.

The reaction times of Table I can best be discussed subject by subject.

M. With the distinctly smaller percentage of right associates for the *FS* syllables, M. unites the slightly longer association time. This indicates that wrong exposure in the case of M. had a genuinely disturbing effect upon the associations with the *FS*

syllables. This inference is confirmed by the fact (not shown in Table I) that M. had 44 very short right-association times in the case of the *RS* syllables as against 31 for the *FS* syllables. As "very short" reaction times are here reckoned those less than 1500 σ. Returning to the table we see that with the somewhat larger percentage of zero cases for the *FS* syllables he combines a much shorter reaction time—the difference amounting almost to two seconds. This clearly indicates that in the case of the *FS* syllables he more readily abandoned the attempt to recall associates. Again in the case of the wrong associates the percentage is greater and the time shorter for the *FS* syllables. This means that the subject, in the case of wrong exposure, was more hasty in naming incorrect syllables. Thus, in the case of M., the figures speak unequivocally for a disturbance of associations by wrong exposure. With no other subject, however, is the disturbance so marked.

G. This subject's times for the *FS* and *RS* syllables differ very little except in the case of the wrong associates (and partly right associates) and the percentages of wrong associates are so small that the difference in the average association times may be purely accidental. With the slightly larger percentage of right associates for the *RS* syllables G. combines the slightly longer association time but into this average time enter fifteen times exceeding 20,000 σ, whereas only six such times enter into the average for the *FS* cases. (M. has only one of these "very long" right-association times and G. has only two "very short" ones.) On the other hand, with the slightly larger percentage of zero cases for the *FS* syllables she also combines the slightly longer reaction time. On the basis of these figures, therefore, it would be impossible to say that G. meditated longer over the reactions to either set of syllables.

W. Virtually the same statements as have just been made for G.'s average times are true for W.'s, excepting that W.'s times differ little even for the wrong associates. It should be noted that W.'s average times are all very short, shorter, on the whole, than those of any other subject. It should also be noted that W. has a larger percentage of zero cases than any other subject

and a smaller percentage of right associates than any except B. These facts show that in the case of W. only the strongest associations had time to function. The introspective data must show whether the subject was frightened or whether she belongs to the class of persons who habitually remember quickly if at all, and, therefore, never spend much time in the effort to recall anything which is forgotten.

B. B. like W. has small percentages of right associates with short average times. B., however, has a larger percentage of wrong associates than any other subject and although her percentages of zero cases are not strikingly large, yet her percentages of wrong associates and zero cases taken together exceed those of any other. B.'s times are, like those of W., notably short for both the wrong associates and zero cases. The average times, like the percentages, differ little for the *RS* and *FS* syllables except for the numerous wrong associates. Here the difference amounts to more than a second. These *FS* cases have the longer association time and the smaller percentage of wrong associates. It would seem, therefore, that B. was less hasty in her reactions in the case of the *FS* syllables. This conclusion is not borne out by the figures for the right associates and the zero cases but here the differences in the times may be accidental. B. is obviously the sort of subject who hastily names the first syllable which comes to mind, whereas W. is the sort who hastily answers "Don't know." Curiously enough, neither B. nor W. has many "very short" right-association times (times below 1500 σ); B. has none at all and W. has only four, three for the *RS* and one for the *FS* syllables.

D. This subject resembles M. as regards right and wrong associates although the disturbance created by wrong exposure is less marked. It is worthy of note that D. had ten "very short" right-association times for the *RS* syllables and only two for the *FS*. In her zero cases, however, she combines for the *RS* syllables the larger percentage with the slightly shorter reaction times. The time-difference may well be accidental.

H. This subject resembles M. as regards right associates and zero cases. The disturbance created by wrong exposure, though

less marked in the percentages and zero-case times is more marked in the right-association times. Here the *FS* time as compared with the *RS* time is not only much longer but much more variable. The *FS* average represents eight "very long" times (over 20,000σ) and seven very short times, whereas the *RS* average represents only one of the former and three of the latter. In the case of the wrong associates H. combines the much longer reaction time with the smaller percentage for the *FS* syllables. The percentages of wrong associates are, however, relatively small as compared with those of M., B. and D.

P. This subject shows larger differences in her reaction times for the *RS* and *FS* syllables than does any other subject. In every class of reactions (except in that of partly right associates which need not be considered seriously) the reaction times are greater for the *FS* syllables. Wrong exposure, then, evidently spurred P. to a greater effort at recall. In the case of the right associates the longer time is combined with the larger percentage and in the case of the wrong associates the longer time is combined with the smaller percentage. The average *FS* time for the right associates covers seven very long times, whereas the average *RS* time covers only four of these extra long times. The number of very short times represented by the former average is four; that covered by the latter is five. It is probable, then, that P. obtained the larger percentage of right associates in the case of the *FS* syllables because she took the longer time to reflect. In the zero cases, however, the longer time combines for the *FS* syllables with the slightly larger percentage.

We may conclude, therefore, from the data in regard to percentages and reaction times taken together that the seven subjects belong to three different classes as regards the effect of wrong exposure. (1) Neither G. nor W. give clear evidence of association-disturbance although one of these subjects has a very high percentage and the other a very low percentage of right associates both for the *RS* and for the *FS* syllables. (2) M. shows clearly a disturbance of associations as a result of wrong exposure, and D. and H. show the same disturbance somewhat

less clearly. (3) P. shows that wrong exposure, whether recognized as such or not, acted as a spur to effort in recall so that any disturbance produced by it was, on the whole, more than overcome. The carelessly reacting subject B. may, though with some uncertainty, be classed with P.

These conclusions receive a certain confirmation from the following figures which represent separately the results for the *FS* syllables which were shown in the "right row," *i.e.*, in the row in which they had stood when the series was learned, and for those exposed in a "wrong" or different row.

Subject	*Wrongly Exposed Syllables*			
	Right Associates with Exposure in		*Zero Cases with Exposure in*	
	Reght Row	*Wrong Row*	*Reght Row*	*Wrong Row*
M.	44%	46%	31%	34%
G.	73	68	21	23
W.	36	37	46	52
B.	27	31	39	32
D.	43	41	29	30
H.	50	49	37	40
P.	54	68	35	24

This scheme shows the following facts: (1) All the subjects, except B. and P., have a larger percentage of zero cases for the wrong-row exposures. (2) Only G., D., and H. have a smaller percentage of right associates for the wrong-row exposures and even in their case the difference is small. It would seem, then, that wrong-row exposure increases the zero cases at the expense of the wrong rather than the right cases, or in other words, that if the syllable is exposed near the place in which it originally stood, the subject is more likely to name some reaction-syllable, right or wrong, than if the displacement is wide. (3) Even W. and more particularly G. show in these figures that they were by no means quite immune to disturbance by wrong exposure. (4) P. and B., the two subjects who, as we have just inferred, were helped rather than hindered by wrong exposure, show a larger percentage of right associates and a smaller percentage of zero cases with wrong-row exposure. In the case of P. the difference is striking.

We may now sum up as follows the evidence in regard to the correlation of right and wrong exposure with right, wrong or

failing association: In the case of some subjects, but not of all, wrong exposure did actually conduce toward wrong recall or toward failure to recall any paired syllable. The disturbance, however, was certainly not enormous even in the case of those subjects who were most affected by it. In the case of two out of six subjects, wrong exposure actually increased the final success in recall.

II. *Did the subjects in general remember the places in which the syllables presented had originally stood upon the exposure-tablet? If so, were instances of right localization more common than instances of right association or vice versa?*

The answer to this question is clear and positive. The numerical data are given in the following scheme:

Subject	*No. Syllables in R S.*	*Per Cent Rightly Localized*	*Per Cent Right Associates*	*No. Syllables in FS.*	*Per Cent Rightly Localized*	*Per Cent Right Associates*
M.	275	67	55	277	44	46
G.	424	92	73	420	91	70
W.	274	94	39	258	86	37
B.	167	72	30	170	42	29
D.	163	88	45	162	62	42
H.	148	87	51	149	78	50
P.	177	84	59	176	81	61

From these figures we may draw the following conclusions:

a. When the syllable presented was exposed in the right place, this fact was realized by all the subjects in the great majority of cases. M. localized rightly only about two-thirds of the *RS* syllables. His is the lowest percentage obtained by any subject. G. and W. rightly localized more than nine-tenths of these syllables.

b. For the *FS* syllables the percentage of right localizations is much smaller than for the *RS* syllables except in the cases of G. and P., in which it is only slightly smaller. The difference is most marked in the cases of M. and B.

c. For the *RS* syllables the percentage of right associates is smaller in the case of every subject than the percentage of right localizations. The difference is most marked in the cases of W. and B. and least marked in the cases of M. and G.

d. For the FS syllables also, the percentage of right associates is smaller than the percentage rightly localized except in the case of M., with whom the percentages of right associates and of right localizations are almost the same. The difference is again least marked in the case of G. and most marked in the case of W.

e. Since the percentages of right localizations are much larger for the *RS* syllables than for the *FS* syllables, whereas the percentages of right associates differ little, there is much greater difference between the percentages of right localizations and right associates in the case of the *RS* syllables.

We may summarize these conclusions in the following statement: The subjects were in general much more likely to realize that an *FS* syllable was exposed in the wrong place than they were to recall the syllable paired with it and they were very much more likely to realize than an *RS* syllable was shown in the right place than they were to recall the other member of the pair.

In regard to individual subjects, it is important to note these two points: First, G. and W., who in the data given in Table I show least disturbance as a result of wrong-place exposure are the subjects who actually localized the largest percentages of syllables. From this we may infer that these two subjects remembered the place of the syllable exposed so clearly that wrong-place exposure had no confusing effect. The prowess of G. and W. in localization must not be attributed entirely to superiority in visualization. G. and W. were the two subjects who, in the test-procedure, were required to give the syllable preceding (not the syllable following) the one exposed. This harder task was imposed upon these two subjects expressly for the purpose of fostering attention to the spatial position of the syllables. Second, M., who in the data of Table I shows the most unmistakable evidence of disturbance by wrong-place exposure, is the subject who localized the smallest percentage of *RS* syllables and almost the smallest percentage of *FS* syllables and is the only subject who actually obtained a larger percentage of right associates than of right localizations for either the *RS* or *FS* syllables. From

this we may infer that M.'s place associations were relatively weak, and that, in the case of the *FS* syllables, they were often blocked by the wrong-place exposure. From this comparison of G. and W. and M., it would appear that disturbance by wrong-place exposure was a mark of weak rather than of strong place associations.

III. *Was right localization actually in the case of individual syllables a concomitant of right association, wrong localization of wrong association and failure to localize of failure of association?*

This question must be answered (*a*) by comparing the cases of right localization, wrong localization and no localization as regards right associates, wrong associates and zero cases and (*b*) by comparing the cases of right and wrong association and the zero cases as regards right localization, wrong localization and failure to localize.

a. The data for comparing the cases of right localization, of wrong localization, and of no localization as regards right associates, wrong associates and zero cases are given in Table II. In this table the words *Indefinite Localization* at the heads of the 5th and 11th columns mean that, in the numbers of cases below, the subjects asserted, rightly or wrongly, that the syllable presented was shown in the wrong place but could give no more definite localization. The cases which are headed *Right Localization* and *Wrong Localization* are all cases in which the subject asserted that the syllable had stood in some particular place, perhaps the third or the seventh. The figures in this table are to be read vertically. The third column may be translated into words as follows: The subject M. rightly localized 316 syllables (out of 552 *RS* syllables and *FS* syllables taken together). Of these, 78 per cent called up right associates, 7 per cent wrong associates, and 9 per cent no associates at all. The remaining 6 per cent (not included in the table) called up partly right associates.[9] The subject G. localized correctly 782 syllables. Of these, 75 per cent were followed by right associates, 4 per cent

[9] Any apparent discrepancies between the figures of Tables I and II are due to the rounding of the percentages into whole numbers.

TABLE II

To Show the Correlation between Right Localization and Right Association

Subjects	Associates	Localization: Right	Localization: Wrong	Localization: Indefinite	Localization: None	Subjects	Associates	Localization: Right	Localization: Wrong	Localization: Indefinite	Localization: None
1	2	3	4	5	6	7	8	9	10	11	12
M.	Total	**316**	**48**	**58**	**127**	D.	Total	**244**	**67**	**6**	**7**
	Right	78%	27%	21%	6%		Right	54%	10%	17%	0%
	Wrong	7	46	24	17		Wrong	15	40	0	14
	Missing	9	23	50	78		Missing	25	43	67	86
G.	Total	**782**	**26**	**0**	**21**	H.	Total	**245**	**27**	**2**	**23**
	Right	75%	31%	—%	10%		Right	60%	4%	0%	0%
	Wrong	4	19	—	0		Wrong	17	26	0	4
	Missing	18	46	—	90		Missing	28	67	50	96
W.	Total	**477**	**33**	**0**	**18**	P.	Total	**302**	**23**	**4**	**11**
	Right	46%	0%	—%	0%		Right	70%	4%	0%	0%
	Wrong	6	24	—	0		Wrong	4	48	0	0
	Missing	45	75	—	100		Missing	21	48	100	100
B.	Total	**192**	**98**	**10**	**31**						
	Right	38%	26%	0%	3%						
	Wrong	28	35	40	32						
	Missing	26	35	40	61						

by wrong associates and 18 per cent by no associates at all. And so on. This table shows the following facts:

1. *Right associates.* (*a*) Of the *RL* (rightly localized) syllables more than 50 per cent called up right associates in the cases of every subject except W. and B. (*b*) Of the *FL* (wrongly localized) syllables not more than 31 per cent called up right associates in the case of any subject. (*c*) Of the indefinitely localized syllables not more than 21 per cent called up right associates in the case of any subject. (*d*) Of the *NL* (not localized) syllables not more than 10 per cent called up right associates in the case of any subject.

2. *Wrong Associates.* (*a*) Of the *RL* syllables not more than 17 per cent called up wrong associates except in the case of B., who was peculiarly prone to name wrong syllables. (*b*) Of the *FL* syllables at least 40 per cent called up wrong associates in the cases of M., D., and P. G., W., and H. localized wrongly only a very few syllables and of these the percentage which called up wrong associates was also small. With B. the naming of wrong associates seems not to have hinged upon wrong localization. P., who localized quite as well as H., seems to have been led astray by wrong localization when it did occur. (*c*) Of the syllables indefinitely localized, none called up wrong associates except in the cases of M. and B., in which the percentages are 24 per cent and 40 per cent, respectively. (*d*) Of the *NL* syllables not more than 17 per cent called up wrong associates in the case of any subject except B., the hit-or-miss namer of syllables.

3. *Zero Cases.* (*a*) Of the *RL* syllables not more than 28 per cent were followed by negative reactions except in the case of W., who was as prone to say "Don't know" as B. was to name wrong syllables. (*b*) Of the *FL* syllables at least 46 per cent were followed by negative reactions except in the cases of M., B., and D., who, as already noted, were much more prone to wrong reactions than the other four subjects. (*c*) Of the syllables indefinitely localized, at least half were followed by negative reactions except in the case of B. (G. and W. never localized syllables indefinitely). (*d*) Of the *NL* syllables at least 78 per

cent were followed by negative reactions except in the case of B. who has 61 per cent. With P. and W. the percentage is 100.

These conclusions may be summarized by saying, first, that there is a correlation between right association and right localization and between failure of association and failure to localize but, second, that the *FL* syllables and the syllables indefinitely localized were likely to call up wrong associates or no associates according to the tendency of the individual subject to name wrong syllables or to say "Don't know."

b. We shall attempt to compare without the use of a table the cases of right, wrong, and no association as regards right, wrong, indefinite and failing localizations. The zero cases included in the discussion are only those in which the syllable presented was declared by the subject to be familiar. Unfamiliar syllables, of course, could not be localized. The results of B. are excluded because this subject seemed unable to pronounce upon the familiarity of the syllables, so that her zero cases are not comparable, as regards localization, with those of the other subjects.

1. *RS Syllables, Right Localization* (*RL*). (*a*) *RS* syllables followed by ***right associates*** were almost invariably localized by every subject. The lowest percentage obtained is M.'s 95 per cent. We have already remarked that M.'s place associations were relatively weak. (*b*) Of the *RS* syllables which had ***wrong associates*** at least 71 per cent were rightly localized except by M., whose percentage is 49. (*c*) Of familiar *RS* syllables which called up ***no associates*** at least 63 per cent were rightly localized by all the subjects and at least 83 per cent by all the subjects except M.

2. *RS Syllables, Wrong Localization* (*FL*)—definite and indefinite. (By ***indefinite wrong localization*** is here meant that the subject asserted that the *RS* syllable was shown in the wrong place but could not assign to it a particular place.) (*a*) *RS* syllables followed by ***right associates*** were almost never wrongly localized. The percentages for M. and D. are 1 per cent; for G., 0.3 per cent; and for the other subjects 0 per cent. (*b*) *RS*

syllables followed by *wrong associates* were wrongly localized in a considerable percentage of cases although even here the percentage of *FL* syllables is never large as compared with the percentage of *RL* syllables. G.'s percentage is only 7. The percentages of the other subjects range from M.'s 16 per cent to P.'s 29 per cent. The fact that P. has the highest percentage should be noted, as we have already seen that P., who has relatively few wrong localizations, was led astray by them when they occurred. (*c*) Familiar *RS* syllables followed by *no associates* were not often wrongly localized. The highest percentage of *FL* cases obtained by any subject is 17.

3. *RS Syllables, No Localizations* (*NL*). (*a*) *RS* syllables followed by *right associates* were practically always localized, at least indefinitely. M. has 3 per cent and G. 1 per cent of cases in which not even the indefinite localization of "right place" or "wrong place" was given. No other subject has any such cases. (*b*) *RS* syllables followed by *wrong associates* were always localized except by M. and H., who have 30 per cent and 7 per cent of *NL* cases, respectively. (*c*) Familiar *RS* syllables followed by *no associates* were usually localized though M. has 31 per cent of *NL* cases. No other subject has more than 6 per cent.

These statements in regard to the *RS* syllables may be summarized as follows: *RS* syllables were in general known to be exposed in the right places. Even when the *RS* syllables were followed by wrong associates or by no associates, they were still in general known to be *RS* syllables by all the subjects except M., whose place associations have been proved weak by other data. Nevertheless, the percentages of right localizations are considerably higher for the cases of right associates than for those of wrong associates or no associates.

4. *FS Syllables, RL.* (*a*) *FS* syllables followed by *right associates* were localized in a large majority of cases. M.'s percentage is only 80 and D.'s only 88. The percentage of no other subject falls below 97. The *RL* percentages for the *FS* syllables are naturally somewhat lower than the *RL* percentages for the

RS syllables, for the right localization of *FS* syllables was naturally the more difficult task. In order to localize an *RS* syllable correctly, the subject had only to feel that the syllable was shown in a familiar place, whereas, in order to localize an *FS* syllable correctly, he had not only to feel that it was shown in an unfamiliar place but also to name some one other particular place out of five or eight possible places. (*b*) *FS* syllables followed by *wrong associates* show a marked fall in the *RL* cases as compared with *FS* syllables followed by right associates. M. has only 7 per cent, P. has 30 per cent, D. 40 per cent, H. 64 per cent, W. 78 per cent, and G. 82 per cent. The disturbance of M.'s place associations by wrong exposure nowhere appears more clearly than here. (*c*) Familiar *FS* syllables followed by *no associates* also show a wide diversity in the *RL* cases for the different subjects. The percentages are: M., 19 per cent; D., 57 per cent; P., 69 per cent; H., 74 per cent; W., 77 per cent; and G., 81 per cent. It is clear that in the case of every subject except G. and W. the percentages are higher than the percentages for the syllables followed by wrong associates. Evidently failures to localize correctly were more frequent in the cases of wrong associates than in the cases of no associates.

5. *FS Syllables with Indefinite Right Localization.* "Indefinite right" localization of *FS* syllables means that the subject detected the wrong exposure without being able to assign the syllable to a definite place. (*a*) *FS* syllables followed by *right associates* were seldom thus indefinitely localized. M. has 10 per cent of these indefinite right localizations and H. 2 per cent. No other subject has any. (*b*) Of the *FS* syllables followed by *wrong associates* 33 per cent were given indefinite right localization by M. None were thus localized by the other subjects. (*c*) Of the familiar *FS* syllables followed by *no associates* 31 per cent were given indefinite right localization by M., 7 per cent by D., 6 by P. and 2 by H., but none by the other subjects. The number of indefinite right localizations made by M. is one of the clearest evidences of the weakness of his place associations.

6. *FS Syllables, FL.* In the case of *FS* syllables, wrong localization was necessarily definite as the reader will see with a

moment's reflection. (*a*) *FS* syllables followed by ***right associates*** were seldom wrongly localized. M. has only 9 per cent and no other subject has more than 8 per cent of such cases. (*b*) For the *FS* syllables followed by *wrong associates* the percentages are as follows: G., 19 per cent; W., 22 per cent; H., 36 per cent; M., 38 per cent; D., 58 per cent, and P., 70 per cent. (*c*) Of the familiar *FS* syllables followed by *no associates* not nearly so many were wrongly localized. The percentages are these: G., 8 per cent; W., 14 per cent; P., 14 per cent; M., 19 per cent; H., 21 per cent; and D., 28 per cent. A comparison of the last two sets of percentages again shows that wrong localization is much more closely bound up with wrong association than with failure of association.

7. *FS Syllables, NL.* (*a*) All the *FS* syllables followed by *right associates* were localized, definitely or indefinitely, by all the subjects except M., who has 2 percent of entire failures to localize. (*b*) All the *FS* syllables followed by *wrong associates* were also localized, at least indefinitely, by all the subjects except M. and D., who have 23 per cent and 3 per cent, respectively, of failures to localize. (*d*) A certain number of the familiar *FS* syllables followed by *no associates* failed of localization in the case of every subject. The percentages are as follows: H., 2 per cent; P., 3 per cent; D., 7 per cent; W., 8 per cent; G., 10 per cent; and M., 31 per cent. A comparison of these last two sets of percentages shows that entire failure to localize is more closely bound up with failure of association than with wrong association.

These detailed statements in regard to the *FS syllable*s may be summarized by saying that a fairly clear correlation appears between right localization and right association, wrong localization and wrong association, and failure to localize and failure of association.

It is evident from the figures given in Table II and from the facts stated in the last few paragraphs that right localization and right association, wrong localization and wrong association, failure to localize and failure of association were, in these experi-

ments, roughly correlated with one another. Nevertheless, as we said in our Introduction, a correlation between right localization and right association does not prove that place associations are highly serviceable as links in the recall of one syllable by another. The results which we have just considered show that the subjects tended to remember both the place of a syllable and its associate or to forget both, but this fact may mean simply that the syllable-sequence and the spatial setting were learned as inseparable parts of one content and not that the place association reinforced the syllable association.[10] Only the introspective testimony of the subjects can directly prove the reinforcement of one association by the other. Before entering upon the introspective data, however, we shall present one more set of numerical data, for these have an indirect bearing upon the exact relationship of right localization and right association.

IV. *Was right localization a concomitant of the feeling that the syllable presented was familiar and ought to evoke an associate?*

If this question be answered in the affirmative, one can easily see that right localization might indirectly contribute to right association by making the subject more strenuous in the attempt to recall the associated syllable even in cases in which the place association did not actually mediate the syllable association. Only in cases in which no associate could be given (zero cases) were the subjects questioned in regard to the familiarity or unfamiliarity of the syllable presented. Syllables which evoked definite reactions were, of course, assumed to be familiar.

a. The data in regard to the familiarity and unfamiliarity of the *RS* syllables which were followed by no associates and in regard to the localization of such of these syllables as were said or assumed to be familiar are presented in the following scheme:

[10] If there be any relation of dependence between right association and right localization, then the former must depend on the latter much more often than the latter upon the former, since right localization is much more common than right association.

Subject	Zero Cases	RS Syllables — Syllables Familiar				Syllables Unfamiliar
	No.	No.	% RL	% FL	% NL	No.
M.	78	35	63	3	31	34
G.	84	81	85	6	6	1
W.	131	111	92	5	3	8
H.	53	39	90	8	3	14
P.	51	30	93	7	0	13

The results of D. are excluded from this scheme as well as those of B. because in the case of D. the experimenters were remiss in asking whether or not the syllable was familiar. The column *FL* covers cases of both definite and indefinite wrong localization. In the cases of nine *RS* syllables M. was unable to pronounce upon the familiarity. No such uncertainties occurred with the other subjects. In a few cases, however, with all the subjects, the question in regard to familiarity was omitted. Less frequently the question in regard to the place of familiar syllables was omitted. These cases, which have not been included in the scheme, account for the fact that the figures for the familiar and unfamiliar syllables do not always add to the total numbers of zero cases, and for the fact that the percentages under the heading *Syllables Familiar* do not always add to 100.

The scheme shows these facts: First, familiar *RS* syllables were rightly localized in a large percentage of cases by all the subjects except M. Second, M. has a very considerable percentage of cases in which familiar *RS* syllables could not be localized, and, indeed, all the other subjects except P. have a few such cases. Evidently, then, definite localization in the case of *RS* syllables was by no means essential to their familiarity.

b. The facts in regard to the familiarity and unfamiliarity of the *FS* syllables which were followed by no associates and in regard to the localization of the syllables which were said to be familiar are shown in this second scheme:

Subject	Zero Cases	FS Syllables — Syllables Familiar				Syllables Unfamiliar
	No.	No.	% RL	% FL	% NL	No.
M.	92	32	19	19	63	33
G.	94	88	81	8	10	4
W.	131	123	77	14	8	5
H.	54	34	74	21	6	20
P.	52	36	69	14	8	16

The column *NL* covers cases of both entire failure to localize and of indefinite localization. In the cases of M., H., and P., the percentage is about evenly divided between the two classes of cases. G. and W. have no indefinite localizations. The cases covered by the column headed *FL* are all cases of definite wrong localization.

This scheme shows, first, that the large majority of the familiar *FS* syllables were also rightly localized by all the subjects except M. and that, except by M., a considerable proportion of the residue of cases were definitely, though not correctly, localized. The scheme shows, second, that in M.'s case, a very large number of familiar *FS* syllables aroused no place association and that the percentage of these cases is by no means negligible in the case of the other subjects, particularly of G. Here again localization appears by no means essential to familiarity.[11]

If the scheme for the *FS* syllables is compared with the scheme for the *RS* syllables, it is clear that about as large a proportion of the *FS* syllables as of the *RS* syllables were familiar to every subject except H. In fact, a larger percentage of the *FS* syllables were familiar to W. This fact seems to show that wrong exposure did not in itself greatly tend toward making the syllable unfamiliar.

On the whole, then, we may conclude, first, that right localization did not, through any connection with the feeling of familiarity, play a very important rôle in recall; and, second, that disturbance of syllable associations produced by wrong exposure was not due to the fact that the wrong exposure made the syllables unfamiliar.

[11] From the fact that our subjects pronounced familiar many syllables which they could not localize and for which they could name no syllable associate, it cannot be inferred that no associated images entered into their consciousness of the familiarity of the syllable presented. A conflict of several ideas of place would be enough to prevent a cautious subject from assigning a definite place to a syllable and yet the very presence of such ideas would prevent the consciousness of familiarity from being imageless.

In using the word *feeling* for the familiarity-consciousness, the writers imply the opinion that this consciousness is at least faintly affective.

Introspective Data

In this section we shall attempt to bring into connection with the numerical data the introspective testimony of the subjects in regard to the character of the imagery in which the syllables were memorized and the intentional use of spatial associations. Only the introspective testimony of the subjects on these points can show definitely whether right localization was a factor in producing right association or was simply bound up with right association as an integral part of the same memory content. We shall also note incidentally the testimony of the subjects to the use of auxiliary associations. In comparing subject with subject, the reader must remember that M., G., and W. learned series of eighteen members whereas the other subjects learned series of only twelve members, that G. and W. were required to give the syllable preceding instead of the syllable succeeding the one presented, that M. and G. had had vastly more practice, and that W. had (during the experiments) considerably more practice, in memorizing than the other subjects. M. is, for obvious reasons, the most important subject but for purposes of comparison it seems best to discuss him last. The other subjects will now be considered one by one.

G. is the subject who has by far the highest percentage of right associates and who ranks with W. in having a much higher percentage of right localizations than the other subjects. Little or no disturbance by wrong exposure appears in the results of G. although with G., as with other subjects, there is a rough correlation between wrong or failing localization and wrong or failing association. G.'s place associations appear to have been too strong to be dislodged by wrong exposure.[12]

G. memorized in terms both of visual and of auditory-kinaesthetic images. Her visual images of syllables are never verbal-visual images of the usual sort but are blotches of color, often variegated. (This subject has colored hearing in a marked de-

[12] G.'s imagery and methods of memorizing have been very fully described in other places. See *Memorizing Various Materials by the Reconstruction Method,* Psych. Review, Whole Number 43, pp. 105 f. and pp. 184-185. *Cf.* also pp. 122 f. and 179 f. of these studies.

gree but all her visual images are blurred in outline, so that she almost never visualizes a word or even a complicated letter entire.) In these experiments she saw each blotch of color in a sort of dark blurred frame, which was probably a reminiscence of the margin of black metal surrounding the syllable when exposed upon the tablet. In recalling the syllables, the visual image was the first to appear but was closely followed by the auditory-kinaesthetic image or by the consciousness of actually speaking the word. When the subject was not sure of the syllables, she often had an interplay of auditory images and more rarely of color images.

The subject consciously availed herself of the unusually good opportunity to form spatial associations but at first the arrangement of the syllables in three rows of six syllables each interfered in a very confusing fashion with her long established habit of grouping the syllables in fours and of visualizing the groups (in series not exceeding thirty-six members) in a single horizontal row. This difficulty was overcome as the experiments proceeded. The subject had long been accustomed, in memorizing series of syllables, either to project the syllables into definite spatial positions in the field of mental vision or to project them upon portions of external space as, for example, upon different parts of a table. The squares of the exposure-tablet furnished a particularly convenient system of compartments for the syllables, even although at first the subject felt as if she would willingly dispense with the exposure-tablet in favor of her own visualizing arrangements.

In impressing the syllables upon herself, G. looked very attentively at the squares of the tablet and also sometimes made use (in internal speech) of such words as "seventeenth" or "next to last." If she thought of the series at a moment when she was not actually looking at the tablet she visualized the blotches of color as emerging, one or two at a time, in a pattern corresponding to the squares of the tablet. It is evident, therefore, that she intentionally "worked" her place associations in memorizing the series. In the test-procedure, however, when she was actually looking at the tablet, she rarely projected the visual (color)

image of a syllable upon it. The synaesthetic image of the reaction-syllable seemed to form behind her eyes. When the stimulus-syllable was presented in the wrong place, the subject was often distinctly conscious of having glanced at its proper place before the syllable paired with it came to mind but often the reaction-syllable emerged with or before the localization of the stimulus-syllable. Apart from verbal images of syllables, internal speech was not very prominent in the recall process.

This subject in these experiments made much, though by no means constant, use of artificial associations, frequently making the syllables into words and then linking the words through their meaning, represented in sketchy concrete-visual terms. Thus, *e.g.*, she connected "bus" and "shipe" as "omnibus" and "ship"—both traveling conveyances. These auxiliary associates were sometimes recalled more readily than the proper syllable. Thus, *e.g.*, the subject connected "chude, quish" by thinking of "quish" as something to be chewed but, when "quish" was presented, she could only remember that she had thought of it as something to eat. These devices seem rarely to have led to the naming of wrong syllables for, in the case of this subject, the number of wrong cases was exceedingly small. G. was probably better able to make, and less able to inhibit, mnemonic devices than any of the other subjects, since she had had long practice in memorizing at slower rates of repetition and had been tempted by the long intervals to fall back on auxiliary associations whenever the series was hard to memorize.

W. is the subject who had the large number of zero cases and the very short reaction times and who ranks with G. in her large number of right localizations. W. is preëminently a visualizer but certainly has at the date of writing, and probably had during the experiments, a certain amount of auditory-kinaesthetic imagery. Her visual-verbal imagery is of the usual type and sharply clear.

In memorizing, W. did not deliberately impress upon herself the spatial positions of the various syllables but learned position as if it were "part and parcel" of the syllable itself. In recalling a syllable, she saw it "tacked into its place on the tablet." In

trying to remember a syllable, she was accustomed to run over parts of the series in mental vision. Thus W. differs from G. in not making deliberate use of place associations to reinforce syllable associations. It would not have been possible for W. to learn a series from the tablet without having the positions of the sequences quite as firmly impressed as the sequences themselves. Thus with W. right localization seems not to have mediated right association and yet to have been its necessary accompaniment. With W., however, more than with any other subject, wrong localization led directly to the naming of a particular wrong syllable. If, for example, W. wrongly supposed that the syllable presented was the 8th, she would be pretty sure to name the 7th syllable as its associate. This tendency, which plainly shows the strength of W.'s place associations, was not marked with any other subject. In the case of M., who, except perhaps for B., was the poorest localizer among all the subjects, mistakes of this class constituted less than ten per cent. of the total number of wrong reactions. M.'s wrong syllables were usually syllables which had some resemblance to those which he should have named or else were syllables which, for some reason, had attracted his special attention. With G., who like W. could localize almost every syllable shown, wrong syllables were nearly always those which had caught her attention, either by their "color" or by their liquid consonants or by their meaning. It is greatly to be regretted that it is impossible to give exact statistics for any subject except M. on this important point. The original records for the other subjects perished in the Wellesley fire.

W. used mnemonic devices to some slight extent and these associations were of the same type as G.'s.

A word remains to be said in regard to the shortness of W.'s reaction times, to which her small percentage of right associates was undoubtedly due in part. (It will be remembered, however, that W.'s task was harder than that of any other untrained subject.) After the experiments were completed W. explained her hastiness as partly due to "fright" and partly to a habit of quickly "giving up" anything which she could not readily recall. She is one of the persons who exhibit celerity in the recall of any

material which still remains at command and who have learned by experience that images which do not come promptly often fail to come even after strenuous efforts to summon them. The subject was often able, however, to give the proper reaction after releasing the lip-key and was thus made to feel that she had not taken time enough to "think." She attributed her nervousness, in part, to the fear that she would not release the lip-key properly.

B. was the subject who had the smallest percentage of right and the largest percentage of wrong associates. B. also had very short reaction times and relatively small percentages of right localizations. She was obviously the poorest memorizer of all the subjects and also gave less satisfactory introspection than any of the others.

The imagery of which she made actual use was mainly "auditory." She also had visual images of the syllables but these images were composed of vague "jumbles" of letters. She had great difficulty in pronouncing the syllables so that the mere reading of them engrossed her attention and left little time for the formation of either place or of other auxiliary associations. Her difficulty in pronouncing the syllables, moreover, made even her auditory images shifting and vague. It is impossible to glean from the data at hand in regard to B. whether or not she ever deliberately made use of place associations.

D. is one of the subjects whose associations seem to have been somewhat disturbed by wrong exposure. Her percentage of right localizations is not particularly large. Her imagery was "auditory." The only visual images which appear to have figured in it were images of the first elements of the syllables. She did not report any intentional use of place associations. She made free use of mnemonic devices, giving meaning to the syllables by virtue of their similarity to English or to French words. In attempting to recall a syllable she would either repeat in internal speech the one presented or try to recall the mnemonic device which she had used for connecting it with its mate.

H., again, is one of the subjects whose associations appear to have been disturbed by wrong exposure. Her percentage of right localizations is large, though not as large as those of W.

and G. H.'s imagery was almost, if not quite, exclusively visual. She herself expressly disclaimed auditory and kinaesthetic imagery. She did not, however, like W., visualize the tablet when thinking of the series or of the place of a particular syllable but seems, like G., simply to have visualized the syllables arranged in rows similar to those upon the tablet. Like G., she made conscious use of place associations both in learning the series and in attempting to recall syllables.

H. made less use of really artificial associations than did any other subject, except perhaps M., but paid much attention to the constituent elements of the syllables, particularly to the qualities of the vowels, comparing them with one another from syllable to syllable.

P. is the subject who was able to recall more right associates in the case of wrong exposure than in the case of right exposure. Her percentage of right localisations is large but no larger than that of H.

P. also claimed imagery almost exclusively visual. Like W., she visualized the tablet distinctly and, when localizing the syllables, projected them into their places upon it.

Like H. and G., she made deliberate use of place associations both in learning and in recall. Like H., she carefully noted and compared the constituent elements of the syllables, especially the qualities of the vowels but she also made free use of artificial associations of miscellaneous sorts.

The subject M., who initiated the experiments, is the only subject with whom disturbance of associations by wrong-place exposure of the stimulus-syllables is very conspicuous. We have already noted strong evidence that his place associations were by no means stronger but, on the contrary, much weaker than those of most of the other subjects. On the other hand, in his total number of right associates, M. ranks third, coming after G. and P. only.

M.'s imagery was "vorwiegend visuell." In the process of recall, images of the reaction-syllables or parts of them were projected upon the squares of the tablet. M. read the series with a very marked intoning, not called for by the simple trochaic

rhythm, and put a distinct caesura after the third and the sixth foot. This intoning undoubtedly tended to give a certain temporal (non-spatial) placing to the various syllables but it also was perhaps an indication of a striving to make poor auditory imagery more serviceable.

M., of course, paid special attention to the spatial setting of the syllables and tried to make all the use possible of place associations. In reading, he both inclined his head slightly and pointed with the index finger of his right hand to the different parts of the series in turn. The *importance* of the place associations thus formed is attested by the numerical results. The experimenter can explain their relatively weak and treacherous character only in the following way: M. had had much practice in memorizing syllables presented one at a time upon a revolving drum and had been accustomed to visualize them sharply by pairs. This habit may have interfered somewhat with the use of place-markers (the squares of the tablet) which were not paired off,[13] and also with the formation of a vaguer and more complex image of a larger part of the series. Certainly we cannot account for the weakness of M.'s place associations, as we can for the weakness of B.'s and of D.'s, by inferiority of visual imagery.

M. occasionally reported the out-cropping of an auxiliary association but his analysis of the syllables into their elements was close and unremitting.

The introspective data will now be summarized in combination with the numerical results.

Conclusions

I. *a.* The introspective testimony shows that four subjects made conscious use of associations of spatial position. These subjects were M., G., H., and P. Of these, M. and H. seem to have been appreciably disturbed by wrong exposure, whereas G. was just perceptibly disturbed and P. seems actually to have

[13] In the experiments of Jacobs (*op. cit.*, p. 51), M. found a drawback to the use of the external-localization scheme in the fact that the little black circles were not paired off.

been helped. On the other hand, disturbance does appear in the case of D. who reports no conscious use of place associations. Thus, it is clear that disturbance by wrong exposure was not correlated with *conscious* use of associations of spatial position.

b. Neither was disturbance by wrong exposure correlated with facility in making spatial associations, for the two best localizers, G. and W., show the least disturbance by wrong exposure, and the poorest localizer (among the subjects whose results need to be seriously considered), namely M., shows most disturbance.

II. *a.* Facility in making place associations seems to have been an asset, though not an unfailing asset, of eye-mindedness.

b. This facility did not involve an intentional use of such associations in recalling syllables presented to the eye. In the mind of W., the syllables and their settings seem to have been too closely fused to have any separate value in suggesting other syllables.

III. Definite localization did not seem to be essential to the consciousness that a syllable was familiar, nor can it be maintained that wrong exposure made the syllables seem unfamiliar and thus deterred the subjects from persistent attempts at recall. For by all the subjects, except one, nearly the same proportion of wrongly as of rightly exposed syllables were pronounced familiar.

IV. *a.* In the numerical results, the sought-for correlation between right *exposure* and right association and between wrong exposure and wrong or negative response is distinctly traceable.

b. A slight correlation also appears, within the results of the subjects taken individually, between right *localization* and right association. But if the subjects be compared with one another, it cannot be said that facility in the localization of the stimulus-syllables was coupled with facility in the recall of the syllables paired with them. One of the two best localizers (W.) is also one of the two subjects who had the smallest percentage of right associates.

V. Correct localization of the stimulus-syllables was vastly more frequent than correct recall of the syllable paired with it. Therefore, if any dependence at all is involved, right association must hinge upon right localization.

If we are to sum up the chief outcome of the experiments in a single sentence, we must say that *associations of spatial position played a clearly demonstrable rôle in recall with all the subjects except B. whose visual imagery was the poorest and (curiously enough) except W., who was the most inveterately eye-minded of them all.* This rôle may be one of help or—if place associations interfere with one another—one of hindrance. The interference may be entirely *subconscious—i.e.,* a mere matter of cortical processes without conscious correlates.

PART II

SPATIAL ASSOCIATIONS IN MEMORIZING

Method and Apparatus

The problem of the second part of our experiments has already been discussed (p. 49). In brief, it was to demonstrate any advantage which might exist in learning series of syllables from the exposure-tablet as compared with the revolving drum, which brought them singly into view behind a screen-slit. On the tablet, the syllables were exposed simultaneously and in conspicuous spatial relations to one another; on the drum, they were exposed successively and all in the same spot. The method of these experiments was precisely the same, *mutatis mutandis,* as the method used in the earlier experiments. Series were learned from the drum and from the tablet according to a cyclic program. The test-procedure for each series took place three minutes after the end of the last reading. The later test-procedure differed from the earlier in this one point, namely, that the stimulus-syllables were all shown—whether the series had been learned from the tablet or from the drum—in one particular place on the *tablet,*—the third square in the second horizontal row. After each reaction, the subject was asked to name the position—the fifth, the ninth, or what not—which the stimulus-syllable had occupied in the series.

It is necessary to lengthen this section only by giving some description of the revolving-drum apparatus. This was made by Spindler and Hoyer and is described in their catalogue under the title "Gedächtnisapparat, Eigenkonstruktion."[1] It was supplied with interchangeable metal drums of three different sizes. Each drum, when in position, rotated about the same horizontal axis by clockwork which was controlled by a falling weight. In

[1] *Apparate für psychologische Untersuchungen,* p. 150. The apparatus is familiar in several American laboratories.

front of the drum was a small screen containing a slit, 5.7 cm. wide by 3.8 cm. high. When this slit was uncovered (by withdrawing a small sliding screen), a single syllable was visible on the white paper fastened about the drum. The rotation of the drum was accomplished by means of a cog-wheel so that it moved in jerks, showing each syllable for a moment and then rapidly replacing it by another. The rate of rotation of the drum could be controlled either by changing the weight or by altering the adjustment of the vane. To both subjects the syllables were presented at the rate of one per second, so that the time occupied in reading the series was the same in the drum as in the tablet experiments. In those with the subject C., the middle-sized drum was used and this drum worked properly. In the experiments with G. (for whom twelve-syllable series were too easy), the largest drum had to be employed. This drum moved irregularly, because some of its cogs were not properly made, and this circumstance greatly annoyed the subject (who felt responsible for the behavior of the apparatus) and often seriously distracted her attention.

Numerical and Introspective Results

The numerical results are presented in Table III.

This table is modelled after Table I. (See pp. 62 and 63.) The only new feature is the fifth column, in which the letters *T* and *D* stand for *tablet* and *drum* respectively. The first line of the table may be translated as follows: The subject G., in memorizing, read from the tablet series of twenty-two nonsense syllables at first three times and afterwards twice each. In the test-procedure, the odd-number syllables were shown so that the subject was required to name the syllable succeeding (not that preceding) each stimulus-syllable. In these tablet experiments, the stimulus-syllables were 292 in number. Of these, 71 per cent called up right associates in an average time of 3640σ. And so on.

One or two explanatory remarks on procedure have been reserved for this place. G. was asked to name the syllable following rather than the syllable preceding the stimulus-syllable in order that her task might be the same as that of C., an unpracticed subject for whom the naming of the preceding syllable was

Table III

To Show the Results of Simultaneous Exposure upon the Tablet as Compared with Successive Exposure upon the Revolving Drum

Subject	Series Length	Repetitions	Syllables Shown	Apparatus	No. of Stimulus Syls.	Right Associates		Partly Right Asso.		Wrong Associates		Zero Cases	
						%	Time	%	Time	%	Time	%	Time
G.	22	3, 2	O.	T.	292	71	3640σ	2	6390σ	6	7150σ	21	8060σ
		3		D.	287	55	2980	3	4130	11	5500	32	7550
C.	12	3	O.	T.	234	47	2670	9	6180	18	6260	27	8310
		3		D.	228	45	3270	6	5350	22	6300	28	7130

supposed to be too hard. As G.'s task was thus made easier than it was in the earlier experiments, it was advisable to make a compensating increase in the length of the series. The length twenty-two was taken because this was the largest number of syllables which could conveniently be presented on the largest of the three drums. The two squares at the right end of the fourth horizontal row on the tablet were left vacant. The readings of the series on the tablet had to be reduced from three to two because with three readings the subject was getting far too many of her reactions right,—*i.e.*, was making only one class of cases, that of right associates.

The discussion of the numerical and of the introspective data will be blended and the results of the two subjects will now be considered one after the other, taking first the unpracticed subject, C.

C. (Josephine Nash Curtis) was an undergraduate student in a second full-year course in psychology. In this work she served both as experimenter and as subject. As a preliminary measure, she was drilled in the use of the apparatus by a series of practice experiments not reported here. Her results show a distinct advantage in learning from the tablet as compared with the drum. With the tablet, she has a slightly larger percentage of right associates with a considerably shorter reaction time (2670 as compared with 3270σ); and she also has a slightly smaller percentage of zero cases with a slightly longer time. She also has, with the tablet, a slightly smaller percentage of wrong associates although the wrong-reaction time is about the same as that with the drum. C. claimed that her imagery was "chiefly visual" although she admitted having "auditory" imagery also. She did not, in the drum experiments, visualize the tablet and project the series upon it after the fashion of inveterate visualizers. (*Cf.* the practice of G. as stated below and that of Jacobs's eye-minded subjects.) Nevertheless, she correctly stated the positions in the series of a considerable percentage of the drum syllables. Her percentages of right placings are given in the following scheme and for convenience of comparison G.'s percentages are included with them:

Subject	*Apparatus*	*Percentages of Right Placings for Stimulus-Syllables Followed by*		
		Right Associates	*Wrong Associates*	*No. Associates*
G.	Tablet	93	50	39
	Drum	88	42	23
C.	Tablet	97	86	65
	Drum	42	25	13

This scheme shows that, on the one hand, C. was by no means oblivious of the position of syllables in the drum series, but, on the other hand, that her placing of the drum syllables was very poor both in comparison with her localization of the tablet syllables and with G.'s placing of the drum syllables. C.'s attention to the place of the drum syllables was probably due chiefly to her being constantly questioned as to their places. But her conscious use of spatial associations in the tablet series is certain. She reported that in learning from the tablet the syllables "paired off naturally," whereas, in learning from the drum, a syllable had no more connection with the one following than with the one preceding it. This she reported in spite of the fact that she read the pairs of syllables from the drum in correct trochaic rhythm. She also said that, in the test-procedure with the tablet series, whenever she could not at once recall the proper syllable, she was accustomed to "try" the stimulus-syllable in different places on the tablet, and that when she "found the right place," the right associate would generally come to mind. With the "drum syllables," she said that "there was no such way of trying to remember" and so she "gave up sooner." C. made some use of auxiliary associations.

With G. the advantage of learning from the tablet appears very great indeed. In the tablet experiments, the percentage of right associates is much greater (71 as compared with 55) and the percentage of zero cases much smaller (21 as against 32). Moreover, she has, with the drum, 11 per cent. of wrong associates, a large number for her. Furthermore, her reaction times for all classes of cases are decidedly shorter with the drum, an unmistakable sign that with the drum a larger number of stimulus-syllables were devoid of any glimmering of associates. As a matter of fact, G.'s method of procedure in the two sets of

experiments was not so very different. When learning from the drum, she intentionally visualized the spots of color representing the syllables in four horizontal lines in a pattern exactly resembling the tablet pattern. In other respects, her method in both sets of experiments was exactly the same as her method in the earlier experiments. (See p. 82.) Her placing of the drum syllables was *bona fide* spatial localization and (as the scheme on page 95 shows) it compares very favorably with her placing of the tablet syllables. In view of the similarity of G.'s method in the two sets of experiments, the enormous advantage of the tablet series as shown in Table III seems at first sight surprising. It is, however, all too easily explained. In the first place, the subject, in spite of much practice in memorizing, had never before learned syllables presented to the eye singly and, so to speak, "on the move." Under the best of circumstances, she would probably have felt a certain nervousness when first learning from the drum. But, in the second place, her eyesight, at the time this work was done, was very poor so that she had great difficulty in reading the syllables quickly enough from the drum, although they were written with India ink and very legibly. In the first and often in the second reading, her attention was wholly taken up with the bare deciphering of the syllables so that none was left for linking them in any fashion. In reading from the tablet, to be sure, she sometimes hesitated but, with the tablet, it was often possible to look back at a half-read syllable even while pronouncing another on the proper metronome-beat. In the third place, G. was frequently vexed by the momentary stopping of the drum, whose irregular behavior no one ever succeeded in entirely correcting. In view of these facts, it is clear that G.'s numerical results, though striking, are not very significant.[2]

[2] As a matter of fact, in certain somewhat similar experiments which are now in progress, this subject is obtaining slightly better results with "internal" than with "external" localization. In these experiments, however, presentation is in both cases aural.

The figures which show the relative familiarity of the tablet and drum syllables in the experiments here reported appear to have been among the records which were burned.

Conclusion

These experiments, as far as they go, tend to show what was indicated by the numerical, and proved by the introspective, results of the earlier experiments, namely, that *associations of spatial position may be not merely a concomitant but also a really mediating factor in the recall of one nonsense syllable by another.* The argument based upon the later experiments runs as follows: *Syllable sequences are better recalled if the series are presented for memorizing in such a fashion as to foster the formation of place associations.* The main argument based upon the earlier experiments is this: *The recall of one syllable by another is blocked if measures are taken to make any place-and-syllable associations which may be formed interfere with one another.*

The results of these later experiments are exactly in line with the findings of Jacobs. The correspondence is the more significant on account of the differences of method. It will be remembered that Jacobs used aural presentation and provided his subjects merely with rows of round black spots upon which they were required mentally to localize the syllables. We, on the other hand, furnished the conditions of perceptual localization. The purport of all three series of experiments, those of Jacobs and our own two series, is the more convincing, because in none of them does the rôle played by place associations loom incredibly large.

Two Studies in Memorizing by Slow And by Rapid Repetition

I.

RATE OF REPETITION AND TENACITY OF IMPRESSION

By E. A. McC. Gamble

With the Assistance of Agnes G. Rockwell, Florence M. Kunkel, and Helen A. Forney

II.

THE RELATIVE AMOUNTS OF FATIGUE INVOLVED IN MEMORIZING BY SLOW AND BY RAPID REPETITION

By Josephine Nash Curtis

With the Assistance of Helen K. Goss and Ethel Caution-Davis

I.

RATE OF REPETITION AND TENACITY OF IMPRESSION

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CONCLUSIONS

I.

RATE OF REPETITION AND TENACITY OF IMPRESSION

Introduction

This paper and the paper which follows are both off-shoots of the writer's "Study in Memorizing Various Materials by the Reconstruction Method."[1] It is unnecessary here to say much of the rough but extended series of experiments made by this method, but it is necessary to call the reader's attention to their general nature and outstanding results, since the problems of the two papers here submitted will be better understood if their historical and logical connection with the earlier work be traced in some detail. This introduction, therefore, will contain (I) a very brief account of the reconstruction experiments, (II) an enumeration of the links which connect the reconstruction work with this present work, and (III) the formulation of the problem of this paper and of the next.

I. By the term *reconstruction method* is meant the procedure in which series of objects are presented to the subject who is afterwards required to arrange them in the order in which they were originally given. This performance may be repeated until the reconstruction is both accurate and unhesitating. In the writer's experiments, the material consisted of scents, of colors, and of nonsense syllables written upon small oblong cards. The results of these experiments are in two respects in marked contradiction to the results usually obtained by the method of complete memorizing, or *Erlernungsmethode,* the method of Ebbinghaus and of Müller and Schumann.[2] In the first place, practice tended

[1] *Wellesley College Studies in Psychology,* Psychological Review, Whole Number 43. Throughout this paper, this work will be referred to as *Memorizing by the Reconstruction Method.*

[2] The nature of this method may be briefly indicated as follows: A series of words or syllables is repeated over and over again until it can once be recited without inaccuracy or hesitation. The first repetitions are made by the experimenter who presents the whole series to the subject. At the end

to reduce the number of repetitions necessary for memorizing by the reconstruction method to the same number for longer and longer series, so that to the practiced learner the length of the series was of surprisingly small importance. In the second place, the number of repetitions required was remarkably small, even with untrained subjects. The number of repetitions necessary for a completely accurate and unhesitating reconstruction rarely exceeded four, even with beginners who were memorizing series of eighteen members, or with practiced learners who were memorizing series of thirty-one or of forty-one. These figures are in striking contrast with the numbers of repetitions, rarely falling below ten, which were necessary for memorizing series of twelve nonsense syllables in the experiments of Müller and Schumann and with the very similar results of other experimenters who have worked with the method of complete memorizing. One should especially recall in this connection the statement of Ebbinghaus: "Whereas I am able, almost without exception, to recite series of six nonsense syllables without mistake after a single presentation, I can recite series of twelve syllables (read rapidly) only after from fourteen to sixteen repetitions, series of sixteen only after thirty, and series of thirty-six only after fifty-five."[3]

II. The connection between the reconstruction experiments (virtually finished in 1905) and the experiments here reported (which were begun in 1910) may be traced (*a*) through other experiments and (*b*) through a theory suggested by them.

a. The contrast just indicated between the results obtained by the reconstruction experiments and by the method of complete memorizing led the writer to make an experimental study of the reconstruction method itself.[4] This study included experiments with nonsense syllables by the method of complete memorizing

of any repetition the subject may begin to recite, but as soon as he hesitates or makes a mistake, the rest of the series is presented to him. The method is more fully described on p. 111 below.

[3] *Grundzüge der Psychologie,* Zweite Aufgabe, p. 651. *Cf. Memorizing by the Reconstruction Method,* pp. 76, 87-89 and 206.

[4] *Memorizing by the Reconstruction Method,* Chapter VI.

and led, by numerical and introspective evidence, to the following conclusions: (1) The small number of repetitions necessary for memorizing series of any practicable length by the reconstruction method was due in large measure (a) to the fact that the subjects were allowed unlimited time for reconstruction and were thus enabled to work with emotional composure and (b) to the fact that the rate of presentation was very slow. The nonsense syllables and colors were presented at intervals of from three and a half to four seconds and the smells at intervals of five seconds. Thus, the rate at which the nonsense syllables were presented was, roughly speaking, only one tenth as fast as the rate used by Ebbinghaus in his classical experiments, and only about one-fifth as fast as the rates ordinarily employed in the method of complete memorizing. (2) Even in this method of complete memorizing itself, the number of necessary repetitions can be very greatly reduced by reducing the rate at which the series is repeated, although this saving of repetitions is ordinarily accomplished at the cost of some waste in the total learning time. The subject learns more in a single slow repetition than in a single rapid repetition but learns more in the rapid repetition in proportion to the time spent upon it.[5] (3) In the method of complete memorizing, also, reducing the rate at which the series is repeated greatly reduces the importance of series length. It would seem on introspective grounds that this fact is due to the lessening of the mutual interference of the associations, the crowding out of one part of the series from the learner's mind by another.[6] (4) Learning by slow repetition under the con-

[5] This result is entirely in agreement with the findings of other experimenters. See the references given on page 157 below.

[6] Ebbinghaus says (if translated): "Many persons can never, in a reasonable time, achieve a perfectly correct recitation of the longer series of nonsense syllables. Some parts are continually thrown into confusion by others. . . . The readings which follow the first readings of the series often seem to bring about only a slight increase in the subject's power to reproduce it. The mutual disturbance of the series members by one another, which is distinctly manifest to immediate consciousness, brings the process of learning to a standstill and only when the whole series has become somewhat more familiar through numerous readings, does a further increase in the number of retained elements take place." *Grundzüge*, p. 651.

ditions of either the reconstruction method or the method of complete memorizing fosters the development of a technique in learning, which could not readily be acquired through learning by fast repetition, but which, once acquired, can be transferred to learning by rapid repetition.[7]

b. The repetition-saving advantage of slow repetition is somewhat parallel to the repetition-saving advantage of distributed repetitions (*Verteilung der Wiederholungen*), an advantage which was demonstrated by Jost. This parallel led the writer to compound out of the doctrines of Professor G. E. Müller and his disciples, (1) a physiological theory of the repetition-saving advantage of slow repetition with (2) a complementary theory of the time-saving advantage of fast repetition. Such a physiological theory is, of course, purely speculative, whereas the tendency of slow repetition to foster the development of technique is a fact of clear introspection. But, however small the value of the writer's theory may be, it is necessary to mention it here because it led directly to the experiments reported in this paper and the next. The theory is set forth in full in the last pages of "Memorizing by the Reconstruction Method." Here it may be summarized in the following statements: (1) An association, in the physiological sense, consists of such a modification of the nerve-path connecting two cortical areas that excitation tends ever afterward to run from one to the other, or, to put the matter still more vaguely, of such a modification of the cortex that the excitory process of one idea tends ever afterward to involve that of the other. The formation of such a modification,—say, by the attentive repetition of two nonsense syllables—requires cortical energy, whatever the nature of this energy may be. If the modification is at all lasting, some process of consolidation

[7] G., the present writer and the principal subject in all these experiments, was able at maximum practice, to learn, by the method of complete memorizing, series of eighty-one syllables in one hour when the syllables were presented at intervals of five seconds, and in three quarters of an hour when they were presented at intervals of one second. The time required for learning syllable series of the same length by the reconstruction method was one hour and a half, but this time included the considerable periods necessary for recording the results of each trial.

or "setting" must take place and this process also requires cortical energy. The amount of nervous energy available in the cortex at any one time is limited. Therefore, when a number of associations, which we may symbolize by letters, are formed in quick succession, the initiation, say, of *e - f* draws energy away from the consolidation of *d - e*. Thus, *d - e* will be less firmly stamped the more quickly, at each repetition of the series, its impression is followed by the impression of *e - f*, and in so far as *d - e* is being consolidated, it will weaken the impression of *e - f*. Thus, a single rapid repetition of a series accomplishes little. Slow repetition has a physiological advantage. *Only multiplication of repetitions can make up for rapidity of repetition.* (2) Rapid repetition greatly increases the perseverative tendencies of the series members. Therefore, a *short* series, if rapidly repeated can be learned for purposes of *prompt recitation* in a relatively short time, since in the case of a short series, the perseverative tendencies of the members may more than make up for the comparative weakness of the associations between them. But the number of words or syllables which tend to perseverate at any one time is very limited. Moreover, rapid repetition tends to increase not only the perseverative tendencies but also the mutual interference of the members—that interference which is so clearly manifest to introspection and which is doubtless the psychic index to the draughting of cortical energy in too many directions at once. Therefore, *long* series cannot be learned by rapid repetition within a "reasonable time" unless the learner has acquired a most unusual technique. (This statement holds, of course, only for the learning of meaningless material.) Moreover, perseverative tendencies,—as (or if) manifested in the "mental echo" of the series—fall away rapidly with lapse of time, running down noticeably in the first thirty seconds and becoming after three minutes negligible as an aid in repeating even a twelve-syllable series. Hence, if a series is to be recited largely in virtue of the perseveration of its members, it must be recited at once and rapidly.

At the time this theory was propounded, the writer held a view of recall, which was afterwards more clearly formulated by

Titchener, who indeed is far from espousing it but sets it forth only to reject it. According to this view three different tendencies may come into play when the word or syllable *e* has been strongly associated with the word or syllable *f* and soon afterward recurs: (1) The impressional tendency of *f,* that is, its readiness to emerge (as an image), "the distance below the conscious limen at which its excitory process is now going on"; (2) the associative tendency, which indexes the strength of the connection between the excitory processes of *e* and *f*; and (3) the perseverative tendency of *f,* which is "a sort of rhythm impressed upon the impressional tendency," such that *f* may "now and again emerge without the aid of the associative tendency." It is this rhythmical, non-associative recurrence which Titchener rejects as unproved.[8] In the theory of the present writer, impressional and perseverative tendencies were not distinguished from each other, but the rhythmical character of something which might well have been called the "impressional tendency" was suggested. In most cases in which the term *perseverative tendency* is used in this paper, *impressional tendency* might be substituted. The writer did indeed (and does still faintly) believe that a *recent, vivid* and *oft-repeated* percept might recur as an image without the aid of association, but has never supposed that a whole series of syllables could be recited *in order* in virtue of perseveration alone. For if equal attention were given to all members of the series, the perseverative tendencies of the last repeated would be the strongest, so that if the series emerged in virtue of perseveration it would be likely to emerge in reverse order—"wrong-end-to." But in the rapid recitation of a much and quickly repeated series, one is conscious of no rearrangement, except in so far as one is conscious of the mental echo of the last few syllables in a sort of polysyllabic nonsense word and is conscious of putting this aside in order to "begin at the beginning." In beginning the series and in reciting it in proper order, perseveration, if operative, must simply facilitate association. One has different feelings or "attitudes" (*Bewusstseinslagen*) when one is reciting a series rapidly repeated many times and

[8] *Cf.* Titchener, *Text-Book of Psychology,* pp. 400-401.

when one is reciting a series slowly repeated two or three times, even when one does not hesitate in either instance. In the one case, one feels as if one were speaking automatically; in the other, as if recitation really involved "voluntary" recall. Do these different feelings, however they may be analyzed in organic and kinaesthetic terms, indicate a difference of kind in the nervous conditions of recall? The question is surely worth asking and trying to answer.[9]

III. The problem of this paper and that of the next are questions which test the theory just outlined,—questions whose answers must buttress or in some degree undermine the theory. The questions are these:

a. If learning by fast repetition involves a severer demand upon cortical energy than learning by slow repetition, then *learning by fast repetition should be the more fatiguing to the subject. Is this the case?* This is the problem of the second paper.

b. If the reason that fast repetition saves time is that a series can, in virtue of the perseveration tendencies of its members, be recited before the associations between the members are firmly stamped, then series learned by fast repetition should not be so

[9] The *locus classicus* for the doctrine of perseveration in normal psychology is Müller and Pilzecker, *Beiträge zur Lehre vom Gedächtniss,* Zeitschrift f. Psych. und Physiol. der Sinnesorgane, Ergänzungsband 1 (1900), pp. 58-78. According to this passage, the term *Perseverationstendenz* means the tendency of a recent, vivid and repeated experience to return to consciousness spontaneously (*frei*), *i.e.,* not in virtue of an associative connection. This is the meaning attached to the term *perseverative tendency* by the present writer, except that she would prefer to say, "not *or not wholly* in virtue of association." For a destructive study of the doctrine of perseveration as thus construed see Foster, *On the Perseverative Tendency,* American Journal of Psychology, 25, pp. 393-426. For the theory of consolidation processes, see Müller and Pilzecker, *op. cit.,* pp. 195-198. See also Müller's paper on *Wiedererkennung und rückwirkende Hemmung,* with the discussion following, in the Bericht über den V. Kongress für experimentelle Psychologie (1912), pp. 216 f. Jost's work is found in the Zeitschrift f. Psych. und Physiol. der Sinnesorgane, 14 (1897), pp. 436, f. His title is *Assoziationsfertigkeit in ihrer Abhängigkeit von der Verteilung der Wiederholungen.* For the suggestion that perseveration tendencies are heightened by rapid repetition, see Ephrussi, *Experimentelle Beiträge zur Lehre vom Gedächtniss,* same Zeitschrift, 37 (1905), p. 202.

well remembered as series learned by slow repetition, series which must be recited wholly in virtue of association and not partly by the aid of perseveration. *Are series learned by fast repetition as well remembered as series learned by slow repetition?* This question constitutes the primary problem of this present paper. A secondary interest lies in securing evidence for a consolidation process in the case of slow repetition. The experimental conditions and data may now be presented.

Materials

Throughout the experiments, the material consisted of "normal" series of "English" nonsense syllables, made in imitation of the normal "German" series of Müller and Schumann.[10] A full description of the English series will be found in the writer's study of the reconstruction method.[11] Series of twenty-four

[10] Müller and Schumann, *Experimentelle Beiträge zur Untersuchung des Gedächtnisses,* Zeitschrift f. Psych. und Physiol. der Sinnesorgane, 6, pp. 99-106.

[11] *Memorizing by the Reconstruction Method,* pp. 20-23. In the series used in 1910-1911, *i.e.,* in the earlier experiments covered by this paper, the combination *qu* was introduced among the initial consonants. In the series used in 1911-1912, *i.e.,* in the last experiments covered by this paper and in all the experiments covered by the following paper, two additional changes were made. The digraph *th* was stricken from the list of initial consonants, because in aural presentation the sound was too easily mistaken for that of *f.* Further, before the terminal silent *e,* which was used to indicate a long sound for the central vowel, *c* was used to give the hard sound of *s.* *S* cannot be used before the silent *e* on account of its phonetic ambiguity and, therefore, in the earlier series the hard sound of *s* had not been used after a long vowel, although the soft sound had been given by *z.* (One could not tell from the spelling whether *bise* should rhyme with *wise* or with *mice* but *bice* is unambiguous.)

These series contain English words. So also do the normal series of Müller and Schumann contain German words. English series made by our rules have, however, at least this one merit, that a learner at all versed in the rules of English phonetics knows how to pronounce them when he sees them and can very easily learn how to spell them when he hears them. (The writer has seen in other laboratories such syllables as *qiv,* which seem unsuitable for most purposes.) It must be confessed, nevertheless, that not all laboratory workers are able readily to apply the laws of English phonetics and that nonsense syllables are in the case of English-speaking subjects by no means so satisfactory a material as they are in the case of German subjects. The German language is phonetic; English phonetic rules have

members were made by joining two series of twelve, end to end, with care that no one sound should occur both in the twelfth and in the thirteenth syllables. The following may be given as a specimen series of twenty-four members: *quoke, pule, bouj, roin, jiv, lame, tene, mite, kug, wox, vesh, haz, moce, quag, poul, vube, hud, raje, shet, lif, keze, toim, wine, yosh.*

Method

Briefly described, our experiments consisted in learning and in relearning series of nonsense syllables by the method of complete memorizing, with aural presentation and with a variety of rates both of presentation and of recitation. In this section, it is necessary (I) to recall the details of the method to the reader's mind, (II) to state the exact manner in which the method was used in our own experiments, and (III) to set forth the procedures by which we strove to test the tenacity of the associations formed in learning the series.

I. The method of complete memorizing or *Erlernungsmethode* is the pioneer method for memory investigation which was devised by Ebbinghaus more than thirty years ago and was elaborated by Müller and Schumann in the early nineties. The writer has taken the term *method of complete memorizing* from Bergström.

The standard features of this method are as follows: A series of words or syllables is presented over and over again, either to the eye or to the ear of the learner, until he can once (or twice) recite the whole in order, without mistakes and without hesitation. At the end of any presentation,

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countless exceptions. Persons who have worked with the writer have persisted to the last in pronouncing certain syllables by analogy with English words not phonetically pronounced, *e.g.*, on making *pove* rhyme with *love* and *dove* instead of with *clove* and *stove*. Another unfortunate tendency is toward pronouncing the strange combinations of letters by analogy with French or German words. Thus, *bouj* may be made to rhyme with *rouge* and *jiv* may be called *yiv*. The writer can see no way of using a large number of different syllables without entailing these disadvantages upon the material.

the subject may begin to recite the series from the beginning, but as soon as he hesitates or makes a mistake, the rest of the series is presented to him. Thus, every repetition or traversing of the series, except the first and the last, may consist partly of presentation and partly of recitation. The first, which, strictly speaking, is not a repetition at all, is necessarily a complete presentation and the last consists in the unerring and unhesitating recitation. In all the publications of this laboratory, the term repetition is used (like the German word *Wiederholung*) to stand for any traversing of the series, whether made up wholly of presentation or wholly of recitation or partly of the one and partly of the other. In reading this paper, it is necessary to keep the distinction between presentation and recitation clearly in mind, since the rates of presentation and of recitation were varied independently of one another.

In the case of visual presentation, a recitation is counted as "unhesitating" when each syllable is named before it can be read by the subject from the revolving drum or other apparatus which is used to bring the syllables singly into view. When the presentation is aural, the distinction between hesitating and unhesitating recitation is harder to draw. The only general statement which can be made is that recitation is called unhesitating when the syllables are recited at the definite rate (however slow) at which the learner is required to recite them. In fact, "unhesitating" recitation is not an indispensable feature of the method. The essential points are rather (*a*) that the series should be repeated from beginning to end until the learner can recite the members in order, without mistakes and within a reasonable time, and (*b*) that when he has once made a mistake or abandoned the attempt to recite, the rest of the series should be presented to him without break. *Prompting* is foreign to the method of complete memorizing proper.

II. In our own experiments presentation was aural. The important details as to rate are as follows: (*a*) In presentation, the experimenter read the series (from the pages of her notebook) in time with the beats of a metronome. (*b*) The rate of

recitation was in some of the experiments restricted and in others unrestricted. When the rate was unrestricted, the subject was allowed to recite the series at any rate she pleased, provided that she named the syllables correctly and in order. The total time occupied in the final recitation was taken with a stop-watch. (See p. 120 below.) (*c*) When the rate of recitation was restricted, it was the same for every series as the rate of presentation for that series. The subject was required to name the syllables upon certain beats of the metronome. (*d*) Altogether five different presentation rates were used. These rates may be called *very slow, slow, moderately slow, fast* and *very fast.* When the very slow, slow, moderately slow, and fast rates were used, the metronome was set at sixty, and the syllables were named respectively upon every fourth, every third, every second and each successive beat. When the very fast rate was used, the metronome was set at seventy-five and the syllables were named one to a beat. When the recitation rate was restricted, the syllables, as already implied, were recited as well as presented at four-second, three-second, two-second, one-second and four-fifths-of-a-second intervals. For the sake of brevity, the following symbols will often be used: *VSP* and *VSR* for *very slow presentation* and *recitation; SP* and *SR* for *slow; MSP* and *MSR* for *moderately slow; FP* and *FR* for *fast;* and *VFP* and *VFR* for *very fast presentation* and *recitation. UR* will be used for *recitation at an unrestricted rate.* (*e*) Whatever the rate of repetition might be, the following rules were followed: (1) At the beginning of work with each series, the experimenter said "Now" upon a given metronome beat and named the first syllable on the next beat but one. (2) At the end of any presentation, after naming the last syllable, she allowed one beat to pass and on the next beat said "Now." On the next beat but one after this signal, if the recitation rate was restricted, the subject was expected to name the first syllable and if she failed, the experimenter named it on the next beat after and then presented all the rest of the syllables at the proper intervals. (3) If, in any attempt at recitation, the subject made a mistake or failed to name a syllable on the proper beat or if, in the case of "unre-

stricted recitation," she said "I don't know," then the experimenter took up on the next beat the presentation of the rest of the series.

In all experiments made by the method of complete memorizing in this laboratory, the records have been kept in the following way: The series is written in a column at the extreme left of the page. A dot or cross is put to the right of each syllable as the subject names it correctly. A dash or "check" is put opposite the first syllable which the subject fails to name—a dash if no syllable is named and a check if the syllable given is wrong. The experimenter always begins with the next repetition a new and parallel column to the right. The number and character of the repetitions can thus be seen almost at a glance. In counting the number of repetitions, the first presentation is always excluded.

III. The tenacity or firmness of the associations formed in learning series at different repetition rates was gauged by the number of repetitions necessary for relearning. In interpreting this general statement, it is necessary to give certain details in regard to the intervals which elapsed before relearning and to note the two procedures which were used in measuring tenacity by the number of repetitions necessary.

a. Throughout the experiments, except in the case of the supplementary sets, the series were, as a rule, relearned two weeks from the day and approximately from the hour at which they were learned, each sitting being given entirely to learning new series or to relearning old ones. If, for example, series were learned on a given Tuesday, the work beginning at 2:30 p. m., the same series were relearned in the same order on the next Tuesday but one, the work beginning at the same hour. If the subject served twice a week, she had in the mean time learned about three times as many other series, one set, say, on the Friday of the first week, and two more sets on the Tuesday and Friday of the second week. Even if she worked only once a week, she had learned or relearned at least one other set of series between the learning and the relearning of any given set. It is important to

note this fact for it is evident that the associations, whose firmness was tested, were weakened not merely by lapse of time but also by retroactive inhibition (*rückwirkende Hemmung*). This circumstance was a most undesirable complication but could not be avoided, if a reasonable time were to be allowed for the subject to forget the series learned and if a reasonable number of results were to be secured. As a matter of fact, the chief subject G. can remember a few series of nonsense syllables (without private review) pretty well for two weeks if no other series have been learned in the mean time, not well enough for perfect recitation without any fresh presentation but quite well enough for a perfect recitation after a single presentation. In a few instances, series were relearned three weeks from the time they were learned. This longer interval, which occurred only when entailed by inconvenient college holidays, was, of course, made to affect alike all sets of series which were brought into comparison. In the supplementary experiments in which the subjects were almost altogether untrained, the forgetting interval was one week, each subject serving three or four times a week.

Both in learning and in relearning, a compensating program, designed to equalize the effects of practice and fatigue for the different repetition rates, was carried out from week to week and as far as possible at each sitting.

b. If we take the number of repetitions necessary for relearning as the gauge of the firmness of the associations formed in learning series at different repetition rates, we yet may proceed in two different ways. (1) The series may all be relearned at the same rate at which they were learned. This procedure has the advantage of making it possible to measure in terms of the percentage of the original number of repetitions which is saved in relearning. The method, however, has serious disadvantages. If in experiments of this type the recitation rate is restricted, and especially if a rapid rate be prescribed, the subject is likely to break down in a certain number of recitations simply from fright. Thus to the repetitions, really necessary for memorizing, a certain fright-increment is added; and this increment, which is likely to be quite as large in relearning as in learning,

obscures the saving in repetitions. Let us suppose that the subject, if emotionally calm, could learn the series with ten repetitions and relearn it with six. Suppose now that two extra repetitions are entailed in each case by stage-fright. This at once changes the proportion 6:10 to 8:12 and the percentage of saving from 40 to 33. If on the other hand, the rate of recitation is unrestricted, even the best of subjects is likely to take advantage of this fact and to allow his attention to slacken. This sagging of attention differs at different sittings and at different moments in the same experimental period. The question of recitation rate is a puzzling matter in experiments of the type under discussion. We shall encounter it again. Another certain objection to this first method of gauging tenacity will appear in the discussion of results. (2) The series learned at different rates may be relearned all at the same rate. In this case, some of them may be relearned at the same rate at which they were learned but some can not. It will, therefore, be impossible to measure tenacity by the percentage of repetitions saved but it will be possible to compare the numbers of repetitions necessary for relearning with one another as they stand. This method has no more serious objection than the fact that it multiplies the sets of experiments which it is proper to make—since all the rates used in learning should, theoretically, be used in relearning—and thus reduces the number of series which it is possible to have in each set.

The experiments fall into three main groups, beside a few supplementary experiments which were made on untrained subjects and need not be taken very seriously. The first and third main groups were made by the first method of procedure; the second group by a combination of the two. Our reason for returning in the third group to the first procedure was simply that we had obtained by it fairly definite results which we desired to test. The various combinations of rates in learning and relearning are shown in the following scheme, in which the abbreviations *Mem. 1* and *Mem. 2* stand for the *first* and *second memorizings,* and the letters *P, R* and *U* respectively for *presentation, recitation* and *unrestricted.*

Intervals in Seconds

Group I				*Group II*								*Group III*			
				Subgroup 1				*Subgroup 2*							
Mem. 1		*Mem. 2*		*Mem. 1*		*Mem. 2*		*Mem. 1*		*Mem. 2*		*Mem. 1*		*Mem. 2*	
P.	*R.*	*P.*	*R.*	*P.*	*R.*	*P.*	*R.*	*P.*	*R.*	*P.*	*R.*	*P.*	*R.*	*P.*	*R.*
4	U	4	U	4	U	4	U	4	4	4	4	3	3	3	3
1	U	1	U	1	U	4	U	1	1	4	4	2	2	2	2
				4	U	1	U	4	4	1	1	1	1	1	1
				1	U	1	U	1	1	1	1	0.8	0.8	0.8	0.8

A glance at the scheme will show that in Group II, two rates were used in the learning and relearning in all possible combinations, making four sets of experiments in all. Comparing two of these sets with each other, *viz.,* the slow-slow set with the fast-fast, one can measure retention by the first procedure. On the other hand, if one compares the slow-slow set with the fast-slow and the slow-fast set with the fast-fast, one can measure by the second procedure. The four different rate combinations were used *pari passu* according to a compensating program, and, hence,—*i.e.,* because the experiments with the slow-slow and fast-slow rates were not separated from the experiments with the slow-fast and fast-fast rates—it may be said that in this group the two procedures were combined. Unfortunately, the number of experiments in each set of this group is almost negligibly small.

Subjects and Experimenters

The details in regard to the personnel and dates of the experiments are outlined in the following scheme, in which a "period" means an experimental sitting of forty-five minutes.

Group I, 1910-1911, first semester. Subject, E. A. McC. Gamble—G. Two periods a week. Experimenters, Helen Forney —F.—and Florence Kunkel—K.

Group II

Subgroup 1, 1910-1911, second semester before Easter vacation. Subjects, G., F. and K., each two periods a week. Experimenters, G., F. and K.

Subgroup 2, 1910-1911, second semester after Easter. Subject and experimenters as in Group I.

Group III, 1911-1912. Subjects, G., two periods a week, and Josephine Curtis—C.—and Ethel Caution-Davis—D., each one period a week. Experimenter, Agnes Rockwell.

Supplementary experiments, 1910-1911, spring term. Subjects, eleven students in a first year course in psychology, who will be designated as Beginners or B. 1, 2, 3 and so on. About eight periods each, three or four a week, enough periods to learn about ten series each under each set of conditions. Experimenters, eleven other students from the same class, who had been laboratory partners of the several subjects throughout the year.

In the experiments made by G., F. and K. (Groups I and II), the work was done by two experimenters at a time, the one presenting the series and keeping the recitation record and the other taking the total learning time with one stop-watch and the recitation times with another. In Group II, subgroup 1, G., F, and K. served as subjects by turns, the other two persons acting as experimenters. (Each combination of experimenters was, of course, obliged to have ready a separate set of nonsense syllable series.) Miss Rockwell and the several beginners worked single-handed.

Of the various subjects and experimenters who took part in the main groups of experiments, F., K. and D. were seniors, pursuing a second full-year course in experimental psychology; C. was a second-year graduate student and assistant in the laboratory; and G. is the writer. The methods of memorizing peculiar to the individual subjects will be discussed in the section on results. Here it is sufficient to point out that all five subjects had had experience in making out the "normal" series of nonsense syllables and that all (for better or worse) knew something of the question at issue. All the five knew from the outset that the series were to be relearned. As a matter of fact, F. and K. served more extensively as experimenters than as subjects; C. was engaged in making the experiments reported in the following paper during the very months when she was serving as subject in this work; and D, was assisting C. (In this con-

nection it may be remarked that Miss Rockwell, who in these experiments served as an experimenter, is the subject R. of the "fatigue work." (See p. 158 below.)

G. is the much-enduring subject G. of the reconstruction experiments, of the experiments by the method of complete memorizing which supplemented them, and of the preceding study in place associations. It is unfortunate that G. has been for so many years the only subject in our laboratory available for long series of memory experiments. The results, to be sure, have not always realized the expectation of this too-well-informed and too-much-interested subject. The objection to G.'s long continued service lies rather in the fact that the results obtained have only a somewhat "individual" value. G. has had from infancy a facility in *verbatim* memorizing exceeding at each stage the average facility of persons of the same age and degree of education, she has attained a very high level of practice, and she has also certain peculiarities of imagery and method which will be discussed in connection with the actual results of these experiments.

The subjects B. 1 to B. 11, who served in the supplementary experiments, were juniors and sophomores. They did not know when the series were first learned that they were ever to be relearned, nor were they familiar with nonsense syllables of any sort. The equally inexperienced experimenters did not make out the syllable series for themselves and were, of course, more or less prone to mispronounce them. All used the same carefully prepared series.

Results

The interpretation of the numerical results depends so much upon the subject's individual method of memorizing that the discussion of the introspective data cannot well be reserved for a separate section but will be merged with the discussion of the figures. Point by point, the numerical data will be followed by the introspective.

Group I. All series relearned at the same rates at which they were learned. Two rates of presentation, very slow—VSP, with

four-second intervals, and fast—FP, with one-second intervals between the syllables. Recitation rate unrestricted. Subject, G. Length of series, twenty-four syllables.

The numerical results may be schematized as follows:

Series Type	*N*	*Learning* *W*	*MV*	*LT* Secs.	*RT* Secs.	*Relearning* *W*	*MV*	*LT* Secs	*RT* Secs.	*Saving in* *W*	*LT*
VSP-UR	38	3.3	0.7	248	33	2.2	0.4	165	34	33%	33%
FP-UR	38	7.0	1.4	314	38	5.9	1.0	240	33	16	24

In this scheme and in those which follow, the letters *N, W, LT* and *RT* are used respectively for *number of series in the set,* for *average number of repetitions necessary for complete memorizing* (*Wiederholungen*), for *average learning time* and for *average final recitation time.* The first line of the scheme may be translated into words as follows: The subject learned and relearned 38 series at the very slow presentation rate (*VSP*) and recited them at an unrestricted rate (*UR*). She learned these series with an average of 3.3 repetitions and a mean variation of 0.7 from this average, and in an average time of 248 seconds; and she made her final recitation on the average in 33 seconds. In relearning, the average number of repetitions was 2.2; the mean variation, 0.4; the average learning time, 165 seconds; and the average recitation time, 34 seconds. Thus, in relearning, 1.1 repetitions and 83 seconds were saved on the average and these savings are 33 per cent respectively of 3.3 repetitions and 248 seconds. The fact has been already noted that in counting repetitions we have been accustomed to exclude the first presentation. The learning time was reckoned with a stop-watch from the *Now* which followed the first presentation to the moment when the subject pronounced the last syllable in her perfect recitation. Thus, *LT* includes the four-second intervals between repetitions and the two-second interval after the first *Now.* (See p. 113.) In taking the recitation times, another stop-watch was started on the *Now* which preceded each attempt at recitation. The values of *RT* are pretty exact; the values of *LT* are merely "gross" since the first watch was not stopped for interruptions of a few seconds' duration.

The figures in the scheme show the following facts:

1. Whatever the rate at which the series were presented, they were finally recited both in learning and in relearning in about the same time. *RT* varies only from 33 secs. to 38 secs. and this value approximates to the time necessary for reciting an *FP* (fast presented) series if recited at the same rate as presented, namely, 25 secs. If a *VSP* series of 24 members was recited at the same rate as presented, the time occupied would be 94 secs. (23 four-second intervals *plus* one two-second interval). From this uniform and moderately short *RT*, we may draw three conclusions: First, the subject preferred to recite the *VSP* series much faster than they were presented, evidently finding very slow recitation unprofitable and wearisome. Second, she could not have made her final recitation of the *FP* series in virtue of perseveration. Not only is the value of *RT* for the *FP* series too great in itself for perseveration-recitation, but it is even rather greater in the first learning than *RT* for the *VSP* series. Third, the subject had mastered the *VSP* and the *FP* series about equally well when she finally recited them. It is important to note before comparing the firmness of the associations in the two cases that we have to do with sets which were equally strong at the time of formation.

2. The *VSP* series were learned with a smaller *W* (average number of repetitions) and a smaller *LT* (average total learning time) than the *FP* series. The fact that the more slowly presented series were learned in the shorter time is only seemingly at variance with the ordinary finding (see p. 105 above) and is due to the unrestricted rate of recitation. The ratio of the times occupied in presenting the *VSP* and *FP* series is, roughly speaking, four to one (94 to 25). The ratio of the *W's* is a little less than one to two (3.3 to 7.0), for the learning and a little more than one to three for the relearning. If, therefore, the series had been recited at the presentation rate, *LT* would have been considerably longer for the *VSP* series. The series were, however, all recited at approximately the same rate and thus the case is reversed. The ratio of *LT* for the *VSP* series to *LT* for the *FP* series is a little less than five to six (248 to 314) for the learning and a little more than two to three for the relearning.

It is, therefore, perfectly clear that it was more economical, both as regards time and number of repetitions, for the subject to learn and relearn series at the very slow than at the rather fast rate of presentation. It is also evident that if the *VSP* series are remembered better than the *FP*, this cannot be due to the fact that the total learning time was longer for the former.

3. If tenacity is to be gauged by the fractions of the original work which are saved in relearning, then the *VSP* series were indeed remembered much better than the *FP*. The saving in *W* is for the *VSP* series 1/3; for the *FP* series, a little less than 1/6. The savings in *LT* are respectively 1/3 and a little less than 1/4. The fact that for the FP series the saving in *LT* is greater than the saving in *W* is probably due to the fact that in the first learning some of the series were very haltingly recited, thus making the first *LT* disproportionately long.

4. *MV* (the mean variation from the average number of repetitions) is noticeably smaller for the *VSP* series than for the *FP*. The uniform and very small numbers of repetitions in the case of the *VSP* series hints at a fact brought out by introspection, namely, that the subject used a technique in learning them which she was unable to make so useful in the case of the *FP* series.

Putting all these facts together, we may conclude (1) *that the FP series were remembered much more poorly than the VSP, but* (2) *that this fact is due not to the rôle played by perseveration in the recitation of the FP series but to some positive advantage possessed by the VSP series.*

The introspective statements recorded in connection with this particular group of experiments are scanty but are sufficient to show that the subject did not depart from her usual procedure in memorizing, which must be outlined here. As a memorizer, G. has two peculiarities. In the first place, she is a marked, indeed rather an extreme, case of colored hearing—to the best of her belief congenital and inherited. In the second place, she habitually localizes the material memorized by a sort of projection of images (spots of color) either in external space or in

the internal field of vision. This habit has been much developed, if not acquired, by practice. In the original series of reconstruction experiments, localization became decidedly external but during the experiments here reported, the subject reverted to localizing in the internal field, when learning by the method of complete memorizing although she still projected the series upon the table during certain reconstruction experiments which were in progress, at the same time. During the experiments reported in the last paper, which were made a year or two earlier than these present experiments, the subject already showed a paramount inclination to internal localization although the conditions were designed to foster external projection. (See p. 83 above.) The subject's schemes of localization are plastic, sometimes change without volition on her part, and can be altered pretty readily at will, whereas the color of letters and combinations of letters (strictly speaking, of their sounds) has been fixed for all time within her recollection and has been transferred from one language to another. (During the third group of these experiments, she deliberately ceased to think of a series of twelve syllables as arranged in a horizontal line from left to right and chose to think of it as arranged in three vertical columns of four syllables each. On the other hand, she could no more make the green word *unity* red or blue than she could change the color of the grass on the campus.) She has, however, beside all this kaleidoscopic imagery, a full outfit of auditory-kinaesthetic images. These images serve to differentiate syllables which are the same in color, for although the syllable images are often particolored and sometimes show traces of black letters upon the colored ground, yet the subject has no well-formed images of letters or even of the shape of words as determined by their spelling. (A word is visualized simply as an oblong, ill-defined blotch of color, more or less long.) Thus, this subject presents in a marked degree many peculiarities of the visualizing learner and yet does not belong by any means to the pure type nor even to any normal mixed type. It may be added that, in anticipating a syllable, in recitation, its color is usually most steadily focused by attention. If the syllable is still "far off" and the recitation

rate is slow, the auditory-kinaesthetic image may be clear, but if the time for anticipation is brief, the color touches off the actual *saying* of the syllable without the noticeable presence of even the most fragmentary internal speech. In the rapid recitation of a well-mastered series, many syllables are not anticipated at all but their colors appear as they are uttered.[12]

In all experiments in which G. has had to learn series presented at different rates, she has greatly preferred the more slowly presented series because the intervals allowed her time "to sort and group the syllables and get them into their places." By *sorting* is meant the clear perception and comparison of the elements of the syllables and by *getting them into their places* is meant visualization of the color spots in pretty definite positions in the external or internal field of vision and in very definite spatial relations to one another.

The foregoing description of G.'s method applies to all the groups of experiments reported in this paper and in that which follows. The records taken in connection with the group of experiments now in question show that G. followed her customary procedure, that she had nothing new to report as to imagery, and that she visualized the color spots as grouped by fours in a

[12] On the imagery and learning methods of this subject, see *Memorizing by the Reconstruction Method,* pp. 105 f., 115 f., and 184 f. See also p. 82 f. of these studies. This subject had also the honor of serving for Professor G. E. Müller and is described in his *Analyse der Gedächtnistätigkeit und des Verstellungsverlaufes,* Zeitschrift f. Psych. und Physiol. der Sinnesorgane, Ergänzungsband 8 (1913), pp. 184 f.

One or two additional points in regard to G. should be noted here. In the last few years (since 1910), her eyesight has become so poor that series of words or syllables can be presented to her only aurally if her learning time is to be closely compared with that of other subjects. Thus, aural presentation has been entailed upon whole groups of observers. Before 1910 she did not greatly prefer either aural or visual presentation. This fact is in itself an evidence of the plasticity of her localization schemes. She could with almost equal readiness visualize syllables according to any spatial pattern in which they might be presented or invent a scheme for herself. She has never been able, however, to image many color spots at once, even as arranged in a scheme so simple as one long line. The spots simply emerge here and there in definite spatial relations to one another, somewhat as objects come out in a garden at night when a spot-light is turned from one to another.

horizontal line running from left to right, and had to make special effort to clinch the last member of one group to the first of the next. They also show these two important points, first, that although G. preferred the *VSP* series, she used precisely the same method of grouping and localizing in both sets of series, and second, that she used no more mnemonic devices in the slow series than in the fast. They were "easier to make but less needed" in the slow series.[13] The fact that the recitation rate was unrestricted heightened G.'s preference for the *VSP* series, since it was not necessary to linger over the presentation of these series just because they were slowly presented.

If now we bring the introspective results to bear on the numerical, we find the small numbers of repetitions and small variations, in the learning and relearning of the *VSP* series, fully explained. *The subject learned the VSP series more readily than the FP because she could more easily carry out her grouping and localizing procedure.* We do not, however, as yet find an explanation for the fact that the saving in time and repetitions was greater in the relearning of the *VSP* series. The two sets of series were mastered about equally well at the end of the first learning—the *VSP* series perhaps a little better, judging from the average recitation times,—but the *VSP* series, originally learned more readily, were relearned more readily in a disproportionate degree. The old groupings of syllables, formed with *less* pains, came back with *much less* pains, when the series were again presented. Unless the difference in firmness of associations is to be accounted for entirely by the rather shorter recitation time of the *VSP* series at the end of the first learning, then

[13] By *mnemonic devices* or *auxiliary associations* are meant throughout these papers *not place associations* but a much more artificial class of extrinsic associations. Some of these devices are easier to make in the case of the more slowly presented series. An instance of this kind is the connection of the syllables *jiv, lame, tene, mite,* by the notion (partly pictorial rather than verbal) of *Jove's* kicking Vulcan out of Heaven and making him *lame* a *tiny* (*teeny*) *mite.* Other artificial connections are easier to make, or rather make themselves, when series are read fast enough to blend into pseudo-words or sentences. An instance would be the blending of *vesh, has* into *vicious.* For the division of auxiliary associations into *Assoziationshilfen* and *Aufmerksamkeitshilfen,* see Ephrussi, *op. cit.*, p. 77.

the *VSP* series have a superiority in the matter of firmness which calls for explanation. We shall, however, make no attempt to explain it until we see whether or not the findings of these experiments are confirmed by others.

Supplementary Experiments.—Some very brief series of experiments made upon the subjects B. 1, B. 2 and B. 3 may be regarded as supplementary to the first main group. The results would scarcely be worth reporting if they did not illustrate certain possibilities in experiments of this sort. The general conditions under which these experiments were made are stated on page 118. The syllables in the series numbered twelve.

The numerical results are given in the following scheme:

Series Type	*Subject*	*N*	*Learning W*	*MV*	*LT* Secs.	*RT* Secs.	*Relearning W*	*MV*	*LT* Secs.	*RT* Secs.	*Saving in W*	*LT*
VSP-UR	B.1	10	7.5	2.5	288	21	3.8	0.6	108	20	49%	63%
FP-UR		9	12.8	1.2	365	20	7.1	0.8	148	19	45	60
VSP-UR	B.2	10	5.5	1.6	264	24	5.3	1.0	127	21	4	52
FP-UR		10	12.2	2.6	330	28	5.5	1.9	147	27	55	55
VSP-UR	B.3	10	5.8	1.6	246	23	4.6	1.2	177	22	21	28
FP-UR		10	6.7	1.7	225	31	5.4	1.5	199	18	19	12

This scheme is to be read exactly like the scheme on p. 120. (*q.v.*). In looking at the figures one should note the following points:

1. The saving in *LT* and, in general, the saving in *W* is relatively great as compared with the figures for G. This fact is easily explained. These subjects had learned only these twenty series of nonsense syllables in the whole course of their lives and might well remember some of them for a week. In the case of B. 2 the saving in *W* is, for the *VSP* series, negligible, whereas the saving in *LT* is great. This means that the subject *recited* these series much faster in relearning than in learning, although the final recitation times are not very different.

2. Like G. all these subjects learned the *VSP* series with the smaller *W* and, with one exception for the first learning, with the smaller *LT*. For them also, learning with very slow presentation was more economical than learning with fast presentation, the rate of recitation being unrestricted.

3. As might be expected in the case of untrained subjects *MV* and *RT* are much more variable than with G. The variations in *MV* are not worth discussing but under *RT* it is important to note that B. 3 recited the *FP* series so much more slowly than the *VSP* at the end of the first learning that she cannot be supposed to have mastered the former as well.

4. B. 1 and B. 3 show the greater saving in *W* and *LT* in the case of the *VSP* series although the superiority of these series in this respect is not very marked. B. 2, on the other hand, shows a slightly greater saving in *LT* and a vastly greater saving in *W* in the case of the *FP* series.

If we turn to the introspection records, we find the cause of this difference between the subjects not far to seek. B. 2 claimed that she learned the series entirely in terms of auditory-kinaesthetic imagery and that with the *FP* series she was "nervous and bewildered." A glance at the figures shows that *W* in the first learning of the *FP* series was in her case very great as compared with the first *W* for the *VSP* series. Evidently, in the first learning, she had difficulty in apprehending syllables rapidly presented, whereas in the second learning, these same syllables were familiar to ear and tongue. Thus in the case of the *FP* series, the saving in *W* is great because the first *W* was particularly large. These figures illustrate a difficulty in gauging tenacity of associations by the amount of work saved in relearning. If with any set of series the number of repetitions required for the first learning is accidentally very high, then the saving of work in relearning is apt to appear large even though the series may not be particularly well remembered.[14] If, on the other hand, the first quotum of work is accidentally small, then the saving in relearning cannot in the nature of the case be very great. We shall later encounter this *difficulty of the accidental first value of W* in its second form.

B. 3 claimed both visual-verbal and auditory imagery and

[14] It should be noted that the relearning of each series is done at a higher level of practice than the learning of that same series. This difference of practice levels is negligible in the case of slowly presented series but with rapidly presented series the unfamiliarity of series when first presented and their familiarity when relearned constitute a serious inequality of conditions.

rather preferred fast presentation, finding the *VSP* series tedious. Since, however, she actually mastered the *VSP* series better in the first learning, it is not surprising that in their case the saving of work in relearning was the greater. B. 1 disclaimed visual imagery but adopted the expedient of naming her fingers with the syllables and was better able to use this device with the *VSP* series. All three subjects grouped the syllables to some extent but B. 2 and B. 3 do not seem to have projected them in any fashion. So far as these experiments go (which is certainly not very far), they appear to be roughly in line with the showing of the first main group.

Group II. Four sets of series: (1) series learned and relearned at the very slow presentation rate (four-second intervals); (2) series learned at the fast rate (one-second intervals) but relearned at the very slow rate; (3) series learned at the very slow rate but relearned at the fast rate; (4) series learned and relearned at the fast rate.

Subgroup 1. Recitation rate unrestricted. Subjects: G., F. and K. Series length: Twenty-four syllables for G. and twelve for F. and K.

The numerical results are presented in this scheme:

Series Type *Mem. 1*	*Mem. 2*	*Subject*	*N*	Learning *W*	*MV*	*LT* Secs.	*RT* Secs.	Relearning *W*	*MV*	*LT* Secs.	*RT* Secs.
VSP-UR,	*VSP-UR*	G.	11	2.7	0.7	199	43	2.2	0.4	185	39
FP-UR,	*VSP-UR*		10	5.0	0.8	216	39	1.9	0.4	138	51
VSP-UR,	*FP-UR*		10	2.4	0.6	188	34	5.1	0.9	219	38
FP-UR,	*FP-UR*		11	5.0	0.5	220	38	4.5	0.9	199	36
VSP-UR,	*VSP-UR*	F.	12	4.5	1.0	201	14	3.3	0.5	143	18
FP-UR,	*VSP-UR*		8	10.6	2.1	319	15	3.4	0.5	125	19
VSP-UR,	*FP-UR*		8	5.5	0.9	228	17	6.3	1.3	169	23
FP-UR,	*FP-UR*		12	9.8	1.6	256	17	6.8	1.3	182	17
VSP-UR,	*VSP-UR*	K.	12	3.9	1.0	189	22	3.6	0.7	131	23
FP-UR,	*VSP-UR*		9	8.5	1.4	242	21	3.5	0.5	145	24
VSP-UR,	*FP-UR*		10	4.2	1.4	163	18	5.3	0.8	139	18
FP-UR,	*FP-UR*		12	8.3	2.1	240	25	6.4	1.0	186	26

This scheme is to be interpreted in the main like the scheme on page 120. Under the heading *Series Type,* the abbreviations *Mem. 1* and *Mem. 2* stand for the first and the second memorizings. No columns have been made to indicate the fractions of

work saved in relearning because the series were relearned at a different rate from that at which they were learned, and, therefore, neither the numbers of repetitions nor, in strictness, the times occupied in learning and relearning are comparable.

The interpretation of the figures is such a baffling problem and the number of series in each set is so small that the writer is tempted to throw out the whole mass of results but is withheld from doing so by honesty since the results are not entirely in accord with the rather neat results of the first group of experiments. It should be noted that the results obtained from F. and K., even though the number of series is rather small, are more reliable than the figures obtained from the beginners. F. and K. had already served as subjects in experiments which might have been included in those of the first group if the number of series had been sufficient and which may, as they stand, be regarded as practice experiments for the work now in question. Aside from this fact, F. and K. were familiar with nonsense syllables and with the problem.

1. The first point to note is that in the case of G. there is much variation in *RT* as compared with *RT* in the first group of experiments. In the first learning, *RT* for the *VSP-VSP* series (series very slowly presented in both memorizings) is noticeably large, whereas in relearning, *RT* for the *FP-VSP* series stands out from the others by its great length, 51 secs. as against 39, 38 and 36 secs. This variation indicates a fact set down in the introspective records, namely, that in recitation G.'s attention fluctuated. This wavering of G.'s attention, which was, so to speak, an abuse of the unrestricted rate of recitation, led to the abandonment of it in the later experiments. It is *probably* responsible for the puzzling nature of the figures in G.'s case. *RT* is more uniform for F. and for K., to whom the experiments were relatively novel, and is much shorter for F. than for K. It is to be remembered that the series learned by F. and K. were only half as long as those learned by G. With this fact in mind, one can see that in the final trial, F. and G. recited at about the same rate—F. a trifle the faster—and that K. recited much more slowly than either.

The next important point is that at each learning very slow presentation was more economical than fast as regards time and, of course, as regards number of repetitions. Thus, for example, K. learned the two sets of *VSP* series in 189 secs. and 163 secs. respectively but required 242 secs. and 240 secs. for the two FP sets. She relearned the two *VSP* sets in 131 secs. and 145 secs. and took 139 secs. and 186 secs. for the *FP* sets. Moreover if we add together the times spent in learning and in relearning the same sets of series (see the figures in the two columns headed *LT*) we find that with one exception (in the case of G.), the entire time spent upon the *VSP-VSP* series is less than the entire time spent upon the *FP-VSP* series and that, with no exception, the entire time for the *VSP-FP* series is less than the entire time for the *FP-FP* series. These experiments, then, are in entire accord with those of Group I in showing that, with an unrestricted rate of recitation, presentation at four-second intervals was more economical than presentation at one-second intervals.

Nevertheless, in spite of the agreement between the two groups, we find the second group diverging from the first when we come to the question of percentages of work saved in relearning. The only series which can be compared as regards work-saving are, of course, the *VSP-VSP* and the *FP-FP* series. (The lines to be compared in the scheme are the first and fourth for each subject.) If we compare the percentages of the original *LT* which are saved in relearning, we find that with F. they are the same (28 per cent) for the *VSP-VSP* and the *FP-FP* series, that with G. the difference is negligible though slightly in favor of the *FP-FP* series (9% as against 7%) and that with K. alone it is decidedly in favor of the *VSP-VSP* series (37% as against 23%). The percentages of the original numbers of repetitions saved are for the *VSP-VSP* and *FP-FP* series respectively as follows: G., 19% and 10%; F., 27% and 31%; K. 8% and 23%. G.'s results are not really in sharp opposition to those of the first group. The saving in repetitions is still clearly in favor of the *VSP-VSP* series and the times are undoubtedly distorted by the subject's lack of attention. With F.

it is clear that neither set of series has an advantage over the other. All that can be said of K.'s results is that the difference between the values of *W* in learning and relearning seems anomalously small.

We now come to the second of the two methods of gauging retention, namely, the comparison of series learned at different rates but relearned at the same rate. (The lines to be compared in the table are the first with the second and the third with the fourth for each subject.) The results are certainly disconcerting. They speak decidedly for the better retention by G. of series rapidly presented. She relearned the *FP-VSP* series in a much shorter time than the *VSP-VSP* series (in 138 secs. as compared with 185 secs.) and with a smaller number of repetitions (1.9 as against 2.2). Similarly the *FP-FP* series have an advantage over the *VSP-FP* series (an LT of 199 secs. as compared with an *LT* of 219 secs. and a *W* of 4.5 as compared with a *W* of 5.1). With K., on the other hand, the *VSP-VSP* series retain the advantage over the *FP-VSP* series and the *VSP-FP* over the *FP-FP*. With F. the difference between the values of *W* is negligible and the *VSP-FP* series have a smaller *LT* than the *FP-FP*, but, as with G., the *FP-VSP* series have a smaller *LT* than the *VSP-VSP*.

Since the number of series in each set of this much divided subgroup of experiments is so small, it seems better to spend no more time in discussing the results until we see whether or not they are confirmed by the experiments of the next sub-group.

Group II, Subgroup 2. Conditions the same as in Subgroup 1, except that the recitation rate was restricted and made the same for each set of series as the presentation rate. Subject G. Length of series, twenty-four syllables.

The results are given in the following scheme:

Series	*Type*		*Learning*			*Relearning*			*Saving in*
Mem. 1	*Mem. 2*	*N*	*W*	*MV*	*LT* *Secs.*	*W*	*MV*	*LT* *Secs.*	*W*
VSP-VSR,	*VSP-VSR*	9	3.9	0.6	394	2.3	0.4	237	41%
FP- FR,	*VSP-VSR*	10	9.8	2.2	297	2.5	0.5	258	
VSP-VSR,	*FP- FR*	10	2.8	0.8	291	8.1	1.1	257	
FP- FR,	*FP- FR*	9	11.9	2.5	356	8.2	1.8	263	31

It is almost unnecessary to say that among the symbols under *Series Type, VSP-VSR, VSP-VSR* means *very slow presentation and recitation, both in learning and in relearning,* and so on. For brevity, the series will be spoken of as *VSP-VSP* series, and so forth. This scheme contains no *RT* columns, for since the recitation rate was restricted to the presentation rate the final recitation of *VSP* series had to take place in 94 secs., counting from the signal *Now,* and the final recitation of an *FP* series in 25 secs. The actual values of *LT* are all somewhat in excess of the times which would have been occupied if there had been no interruptions, such, for example, as were occasioned by the subject's breaking in to ask, "*Min* or *Nin?*" when she failed to grasp the first element of a syllable. To take an actual instance of divergence, the first *LT* for the *VSP-VSP* series should be 375 secs. and is 394 secs.

In discussing the results the first, though not the most important, point to note is that the slowly presented series no longer have a uniform advantage over the rapidly presented series as regards learning time. One set of series very slowly presented took longer in the first learning than either of the two sets rapidly presented. In relearning, one set very slowly presented took one second longer than one of the *FP* sets. Moreover, the total time spent upon the *VSP-VSP* series, in learning and relearning, is longer than the total time for any other set. It must be remembered that, in these experiments, the subject was compelled to recite the *VSP* series very slowly, whether she could have recited them faster or not, and that at the prescribed rate the recitation of a *VSP* series took upwards of four times as long as the recitation of an *FP* series (94 as against 25 secs.). Hence, *LT* for the *VSP* series cannot be as small as *LT* for the *FP* series unless *W* for the *VSP* series is only about one-fourth as great as *W* for the *FP* series. It will also be remembered that this subject, in the earlier experiments, made her final recitation of *VSP* and *FP* series in about the same time, namely, thirty-odd seconds. In face of these facts, we are compelled to conclude that *there is little profit in comparing the learning times of series which must be recited at different rates. We never can tell how*

much faster than the slower rate the subject could have recited, nor, for that matter, what the consequences of artificial retardation may be in the way of inattention.

As regards *W*, the *VSP* series retain their old decisive advantage over the *FP*. Roughly speaking, *W* for the *FP* series is about treble the *W* for the *VSP* series. In these experiments, slow repetition appears to have accomplished, in proportion to the time spent upon it, nearly as much as fast repetition, though not more.

The *VSP-VSP* series have regained their old advantage over the *FP-FP* as regards the percentages of repetitions saved in relearning, 41% for the former and 31% for the latter.

Although the differences are small, the *VSP-VSP* series have in relearning a smaller *W* and *LT* than the *FP-VSP* series, and the *VSP-FP* series have the same advantage over the *FP-FP*.

In view of these facts, we must conjecture that in the experiments of the preceding subgroup, G., who confessed to fluctuating attention, was less on the alert in the relearning of those series which were really the more familiar, namely, those which were very slowly presented in the first learning.

F. and K. also served as subjects in these experiments, but as they learned only four series of each type, their results cannot be taken seriously. F.'s averages chance to be exactly in line with G.'s; K.'s are not.

The numerical results of this whole group of experiments are so scanty that little time need be spent upon the introspective records. The only important points in G.'s statements are her confession of slack attention (of "taking it easy") in the recitations of the first subgroup, and her remark that in the fast recitations of the second subgroup she sometimes "could not read the mental copy fast enough to get the syllables on the right beats", whereas at other times she purposely avoided "looking ahead" because if she "failed to see a color spot coming" (in its place on the line), she was frightened and apt to break down. This remark testifies to the paramount attention paid to the visual images of the syllables and to their spatial projection in the internal field.

F. and K. were both visualizers, also. K. made more use of internal speech than F. who instantly translated the aurally presented syllables into visual-verbal images and then often mispronounced them in reading them off. F. was "sure" she had auditory images "of the *g's* and *j's*," a declaration which certainly implies a dearth of auditory images. It is curious that F., who was the most exclusively eye-minded of the three subjects, was also the most rapid reciter. Both F. and K. grouped the syllables and F. projected them upon a horizontal line from left to right, grouping the first four together and pairing the next two and the very last two. K. used mnemonic devices both in the *VSP* and the *FP* series; F. used extremely few. K. like G., liked the *VSP-VSP* series best of the four sets, whereas F. preferred the *VSP-FP*, saying that in relearning it was tiresome to have to go over a series slowly when one already knew part of it.

Before we pass to the third and last main group of experiments, we should glance at the results of some experiments on beginners, which are supplementary to the work of the first subgroup of the present group, that in which the rate of recitation was unrestricted. The general conditions of these supplementary experiments are stated on p. 118. The following scheme gives sufficient indication of the series types used and of other details except the number of syllables in the series, which was twelve.

Series Mem. 1	*Type Mem. 2*	*Subject*	*N*	Learning *W*	*MV*	*LT* Secs.	*RT* Secs.	Relearning *W*	*MV*	*LT* Secs.	*RT* Secs
VSP-UR,	*FP-UR*	B. 4	10	10.5	3.4	459	15	8.1	2.3	204	15
FP-UR,	*FP-UR*		9	16.6	3.7	405	14	7.4	1.5	176	14
VSP-UR,	*FP-UR*	B. 5	10	7.2	1.6	390	30	9.5	2.5	234	16
FP-UR,	*FP-UR*		10	15.0	3.6	513	27	11.1	2.9	267	20
VSP-UR,	*FP-UR*	B. 6	10	3.5	0.9	235	20	3.2	0.7	168	26
FP-UR,	*FP-UR*		9	6.2	1.4	307	17	3.9	0.8	178	28
VSP-UR,	*FP-UR*	B. 7	10	5.2	0.7	242	30	4.7	1.1	159	21
FP-UR,	*FP-UR*		9	8.4	2.0	318	24	6.0	1.3	205	20
VSP-UR,	*FP-UR*	B. 8	10	5.8	1.9	303	27	4.7	1.5	156	21
FP-UR,	*FP-UR*		9	10.6	2.4	475	26	5.6	1.1	188	22
VSP-UR,	*FP-UR*	B. 9	10	5.2	1.2	240	26	4.1	1.1	135	23
FP-UR,	*FP-UR*		9	9.1	1.9	265	29	4.3	0.8	108	27
VSP-UR,	*FP-UR*	B. 10	10	8.8	2.4	330	21	7.2	1.2	213	30
FP-UR,	*FP-UR*		10	14.1	2.9	375	24	7.2	1.4	195	15
VSP-UR,	*FP-UR*	B. 11	10	5.7	1.0	285	22	6.5	1.0	118	21
FP-UR,	*FP-UR*		10	7.9	1.3	283	22	5.0	1.4	169	16

In these experiments we find eight untrained subjects learning some series with a slow and others with a very fast presentation rate and relearning all at the same fast rate. All the subjects in the first learning mastered the *VSP* series with the smaller *W*, and all the subjects, except B. 4 and B. 11, had the smaller *LT* with the *VSP* series. From the values of *RT* we judge that all the subjects, with the probable exception of B. 7, knew the two sets of series about equally well at the end of the first learning. All, excepting B. 4, B. 10 and B. 11, relearned the *VSP-FP* series with the smaller *W* and all, except B. 4, B. 9 and B. 10, with the smaller *LT*. The differences are in some cases considerable. Only in the cases of B. 4 and B. 10 do we fail to find any advantage for the *VSP-FP* series over the *FP-FP*, either in the second *W* or in the second *LT*, and in the case of B. 10 the two values of the second *W* are equal. Turning to the introspective data, we find that only B. 4 and B. 10 expressed a preference for fast over very slow presentation. All the others objected to fast presentation because it made them "nervous" or because it made the syllables "a confused series of sounds" or because it "gave no time for review" (B. 7) or because it allowed less time for naming fingers with syllables. On the other hand, both B. 4 and B. 10 objected to very slow presentation as unnecessary and tiresome, though it should be noted that neither was a facile memorizer as compared with B. 6, B. 7, B. 8, B. 9 or B. 11. All these subjects except B. 9 were visualizers and all except B. 8 grouped the syllables in some fashion. B. 8 spoke of "reading off" the syllables but appears to have seen them in an unbroken line or column. All, except B. 7 and B 8, used some form of mnemonic device but no one of them, except possibly B. 7, made any great use of spatial associations.

From the second main group of experiments and its supplement, we may draw the following conclusions:

(*1*) *As in the first main group of experiments, the chief subject G. retained associations formed by the presentation of syllables at four-second intervals better than those formed by presentation at one-second intervals. This is shown by the comparison both of series learned at different rates and relearned at*

the same rate as learned and of series learned at different rates but all relearned at the same rate.

(2) This better retention of the very slowly presented series cannot be considered a personal peculiarity of G., since we find unmistakable evidences of it in the fragmentary results obtained from other subjects. Nevertheless, the results obtained from F., B. 4 and B. 10 suggest that all subjects are not like G. in this respect.

(3) An unrestricted rate of recitation is dangerous in experiments of this type on account of the inequalities of attention which it permits and yet it is a convenience in giving us in the final recitation times a clue to the subject's relative mastery of different sets of series.

Group III. All series relearned at the same rates at which they were learned. Four rates of presentation: (1) *slow —SP,* with *three-second intervals; (2) moderately slow—MSP, with two-second intervals;* (3) *fast—FP, with one-second intervals; and* (4) *very fast—VFP, with eight-tenths-of-a-second intervals between the syllables. Series recited at the same rate as presented. Subjects, G., C. and D. Number of syllables in series, twelve for all alike.*

Series Type	Subject	Period	N	Learning W	Learning MV	Learning LT Secs.	Relearning W	Relearning MV	Relearning LT Secs.	Saving W	Total LT Secs
SP- SR	G.	1	18	2.9	0.6	107	2.6	1.0	96	10%	203
MSP-MSR			17	4.1	0.9	108	3.8	1.1	100	7	208
FP- FR			18	8.0	1.8	125	6.2	1.2	96	23	221
VFP-VFR			17	9.6	2.3	121	8.4	2.1	105	12	226
SP- SR		2	42	2.4	0.6	88	2.2	0.6	81	8	169
MSP-MSR			42	2.8	0.8	73	2.9	0.8	75	–	148
FP- FR			42	5.5	1.5	87	4.4	1.0	67	20	154
VFP-VFR			42	6.9	1.3	86	6.8	1.2	85	2	171
SP- SR	C.		23	4.7	1.5	176	4.0	0.8	149	26	325
MSP-MSR			22	6.1	2.4	162	4.5	1.2	119	18	281
FP- FR			23	9.9	2.6	155	7.3	1.9	114	26	269
VFP-VFR			24	14.0	4.0	177	9.0	2.1	113	36	290
SP- SR	D.		13	6.7	1.5	252	5.8	1.4	217	13	469
MSP-MSR			15	7.9	2.1	210	7.4	2.3	197	6	407
FP- FR			15	11.7	2.9	184	8.8	2.2	140	25	324
VFP-VFR			16	14.4	2.4	182	9.7	1.6	122	33	304

In this table, the times given under the *LT* headings are not the learning times actually recorded but times which have been calculated on the basis of the numbers of repetitions. The original records of these experiments were burned and the time averages were not entered in the table of results, which (with a scanty record of introspection) now remains in the hands of the writer. For practical purposes, the times entered in the table probably resemble the real times closely enough but they must all be slightly lower than the real times. (*Cf.* p. 132 above). For the convenience of the reader the values of *LT* in learning and in relearning have been added together and entered in a column at the extreme right of the table.

As the recitation times were restricted, the times occupied in the final and perfect recitation were respectively for the *SP, MSP, FP* and *VFP* series, 35 secs., 24 secs., 13 secs., and 10.4 secs., counting from the signal.

As represented in the table, the results of G. fall into two sections. The experiments covered by the first section were made before Christmas and the results worked out in the holidays. The outcome was so surprising to the experimenters that the results obtained after Christmas were averaged separately to see if they would make the same showing. When we scrutinize the figures, we see that they amount for G. almost to a reversal of the findings of the earlier experiments but that the number of series is so large that the work cannot be set aside. Moreover, the results of the other two subjects are quite in line with the new showing of G. In detail, the points to be noted are as follows:

1. As in the preceding experiments, *W* increases with the presentation rate. This is true for all the subjects, both in learning and in relearning, and is the common finding when series are learned at different repetition rates.

2. The more slowly presented series do not have such an advantage in *W* that they have an advantage in *LT* as well. We find that in each period of G.'s work, the learning times differ little among themselves and the relearning times still less. In the first period, the average total time spent upon the different sets

of series rises slowly but steadily with the rate—from 203 secs. for the *SP* series to 226 secs. for the *VFP* series. In the second period, the longest total time—171 secs.—was spent upon the *VFP* series, but the *SP* series are a close second, and then comes a considerable drop to the *FP* and *MSP* series—from 169 secs. to 154 secs. and 148 secs. In the cases of C. and D., the more rapidly presented series have a clear advantage in *LT*. With D., the advantage is very marked since *LT*, both in learning and in relearning, decreases steadily and, in relearning, decreases considerably with the increase of presentation rate.

3. As regards the percentage of work saved in relearning, the more rapidly presented series, not the more slowly presented, have in these experiments the marked advantage. With all three subjects the saving is least in the case of the *MSP* series. This fact is hard to explain and is very conspicuous. With G., the saving is greatest in the case of the *FP* series. In both sections of the figures, the advantage of these series is marked. In the first section, the difference between the *SP* and *VFP* series is negligible but, in the second section, the saving in the case of the *VFP* series is itself negligible. With C. and D., the *VFP* series show decidedly the greatest saving. In C.'s case, the *SP* and *FP* series rank together but, in D.'s case, the *FP* series are greatly ahead of the *SP*. In G.'s case, the numbers of repetitions are smaller, both in learning and in relearning, than those of the other subjects and the saving in repetitions is also less than theirs. The saving in repetitions is greatest with C., although her numbers of necessary repetitions are smaller than D.'s.

These surprising results raise three questions: (1) How is the divergence of G.'s results from those obtained in the experiments of the year before (Groups I and II) to be explained? To be sure, the numbers of series in Group II were not large but, on the other hand, those in Group I were considerable—thirty-eight in each set as against forty-two in the second section of these experiments. (2) Is the advantage of the more rapidly presented series in the cases of C. and D. (an advantage which is marked in comparison with their showing in the case of G.

even in these experiments) an indication of an "individual difference"? (3) What is the meaning of the fact that the *MSP* series, and not either the *VFP* or the *SP* series, show the minimum of saving in relearning? In the discussion of these questions such introspective data as remain in the possession of the writer will be interpolated.

(1) As regards the first question, it is probable that G.'s results are not really so much at variance with her showing in the earlier work as appears on the surface. Three facts are to be taken into consideration. In the first place, G.'s percentages of saving are, in these experiments, small as compared with her percentages in Group I and in the second subgroup of Group II. (See the schemes on pp. 120 and 131.) They are also small as compared with the percentages of C. and of D. As a matter of fact, G. was memorizing so many series at the time when this present work was done that her retention was very poor. She was serving as subject in the "fatigue experiments" described in the following paper and was very much aware of the displacement of one series of impressions by another. This fact does not explain the advantage of the *FP* series but simply shows that these experiments were made under conditions different from those of the preceding year, which were made when G. was learning no other series of nonsense syllables. In the second place, G. was, in these experiments, using somewhat different methods in learning the more slowly presented and the more rapidly presented series. With the slower series, she was using her old device of projecting the color spots which represented the syllables in a definite pattern in the mental field of vision. In the second section of these experiments, she ceased to project the spots in a single horizontal line and, for the express purpose of emphasizing spatial relations and comparing colors, took to projecting the spots in three vertical columns of four syllables each, so as to bring the first, fifth and ninth syllables, which were the initial syllables of each group, side by side from left to right in the same line, and so as to bring the syllables second in each group side by side in the line below, and so on. She tried to use the same method in the more rapidly presented series and had

usually succeeded in projecting the syllables before the final recitation. She had, however, a great deal of trouble in "hearing" the syllables of the *FP* and *VFP* series and, in her perturbation, caught at every mnemonic device within mental reach. If some of the syllables could thus be bound together and disposed of, her attention could be concentrated on "getting hold" of the rest. In relearning, these artificial associates frequently came back to mind, whereas the more slowly presented series often seemed entirely unfamiliar. The artificial associates differed from series to series; the framework of the syllable pattern was the same for all series and gave little assistance in reviving old impressions.[15] In the third place, we meet, in the case of the *SP* series, "the difficulty of the accidental first value of *W*" mentioned on p. 127 above. After all, G. was memorizing series of twelve syllables only and was memorizing at a slow presentation rate. This task had become very easy work for her. In the majority of cases, it was performed with two presentations. As the subject frequently remarked during the year in which these experiments were made, the first slow presentation enabled her "to take stock of the syllables in the series" and the second enabled her "to link them together." A third was entailed only by nervousness in recitation. But even in relearning these two presentations seemed to be necessary except when the subject was in exceptional learning trim. She had to "see what was in the series all the way to the end" before she could "connect it up." To put the matter numerically, the value of the first *W* had almost reached the lower limit for *W*, namely, one, and the value of the second *W* could not fall far below it. Putting all

[15] The reader in these experiments was a Southerner of "opened vowels and softened consonants," and the subject, though of the Middle West by birth and speech, could not learn the syllables so well when they were presented by her as when they were presented by either of the two New Englanders who read in the "fatigue experiments." While she was learning the 70 series of the first section, she learned 116 series in the fatigue work, half of them *SP* and half *FP* series. *W* for the *SP* series was 2.7 as against 2.9 in these experiments, and *W* for the *FP* series was only 5.6 as compared with 8.0. It is evident that in the aural presentation of series, considerable inequality of conditions may arise through the provincial differences of pronunciation which are common even among educated persons.

these facts together, the writer concludes that *in these experiments the superiority of the more rapidly presented series was accidental, and, therefore, that these experiments do not overturn, although they certainly do not support, the conclusions to be drawn from the earlier groups.*

(2) We must answer the second question in the affirmative. *In the cases of C. and of D., the advantage of the more rapidly presented series, not only in regard to total learning time but also in regard to the percentage of the original work saved in relearning, does really indicate a genuine individual difference between these subjects and G. The difference is probably rooted in the degrees of attention paid to the more slowly and to the more rapidly presented series.* The difference in attention may be traced to the difference in imagery. In one respect, this difference *may* have worked against the better retention of the more rapidly repeated series by C. and D. C.'s imagery, like G.'s, consisted of visual-verbal images (C.'s were of the normal type) blended with internal speech, but, unlike G.'s, C.'s imagery became decidedly auditory-kinaesthetic in the case of the more rapidly presented series. C. claimed expressly that, in the case of the fast series, she was helped by auditory-kinaesthetic "perseveration," that is, by the mental echo of the series in internal speech. Even G. remarked that sometimes a very rapidly presented series would seem to "say itself," but usually in the recitation of these series G. read from her mental copy and occasionally complained that the color spots would not form fast enough in the internal field. D. took a somewhat antagonistic attitude throughout the work and maintained that she "had no imagery at all" but that she could have visualized the syllables if she had liked the work. From this statement, we may glean, first, that she had little or no *visual* imagery and, second, that in reciting she took no pains to anticipate syllables. Her relatively short learning times in the case of the *VFP* series indicate that internal-speech perseveration came into play in her case also. Now the writer assumed at the outset of this paper that if series were recited with the aid of perseveration they might be recited before the associations between the syllables were firmly impressed, and

that such series would necessarily be quickly forgotten since perservation is essentially evanescent. If this assumption is correct, it is obvious that the better retention of the more rapidly presented series by C. and D. cannot be explained by the more conspicuous presence of the kind of imagery in which an aurally presented series most naturally tends to perseverate.[16] Indirectly, however, the difference in imagery was an important factor in determining the sorts of attention paid to the slower and to the faster series by C. and D., on the one hand, and by G., on the other. G. learned the slower series *con amore* because she could readily use her color-spot pattern. In presentation, the long intervals never seemed wasted because they were occupied in putting the syllables into their places in the pattern and in comparing the colors of syllables in different positions. In recitation, indeed, the long intervals were somewhat trying but not sufficiently so to make G. prefer the faster series. On the other hand, in the cases of C. and D., the long intervals were worse than wasted, since they evidently allowed time for attention to waver seriously. After a given syllable was presented or recited, the subject had time in a three-second interval to think of the next syllable, if she knew it, and then to think of something else, and she was apt to be thinking of that something else when the time came to hear or say that next syllable. C. expressed a marked preference for the faster series because the slower series were "hard to attend to." D. said that she "hated all alike," but evidently she did pay closer attention to the faster series. Otherwise the *FP* and *VFP* series could not possibly have had their great advantage in the matter of total learning time. Here, then, is the crucial difference between the subjects. C. and D. remembered the faster series better because they gave much more sustained attention to learning them and thus made stronger associations between the syllables. Unfortunately, we have, in this group of experiments, no comparable recitation times to serve as a clue to the strength of the associations when the series of the

[16] An eye-minded subject may undoubtedly have visual perseveration even in the case of aurally presented series, since the aural impressions may instantly be translated into ocular terms.

various sets were perfectly recited. The time of recitation was restricted and every series had to be recited just as fast and just as slowly as it was presented. *It is very probable that the difference in recitation rate led in itself to a difference in the initial strength of the associations, since the slow series could be recited in virtue of very weak associations.*

Incidentally and to complete the introspective data, it may be remarked that C. grouped the syllables in fours as did G., but made no mention of spatial projection. She used more mnemonic devices in the slower series than she used in the faster series, a fact which must in itself have made for the better retention of the slower series (actually less well remembered). D. does not appear even to have taken pains to group the syllables. She said that she was helped by artificial associations when they occurred to her but that she took no trouble to make them.

(3) The minimum saving in the case of the *MSP* series is hard to explain but Miss Rockwell makes the plausible suggestion that, in the cases of C. and D. these series were heard and recited with the least attention, since they required neither the effort to attend which was demanded by the still slower series nor the very alert attention which was necessary if the syllables of the faster series were to be grasped as presented and to be recited on the proper beats. This conjecture in regard to C. and D. is borne out by the fact that G. considered the learning of the *MSP* series particularly easy and pleasant. In the relearning, these series seemed more unfamiliar than any of the others to G., who said at the time that they were "hoodooed."

On the whole, then, we may conclude (*1*) *that this group of experiments gives no evidence that series of nonsense syllables slowly presented and recited are better remembered than series more rapidly repeated;* (*2*) *that, in view of the circumstances under which they were made, they should not be regarded as overturning the conclusion that G. remembered series learned by slow repetition better than those learned by fast repetition;* (*3*) *that two out of the three subjects certainly did remember the more rapidly repeated series better than those more slowly re-*

peated; but (4) that they did so probably because they paid better attention to the faster series and thus formed associations of superior initial strength. The experiments do not preclude the possibility that if these two subjects had really been able to recite the slower series as readily at the outset they might have remembered them as well as they remembered the faster series.

Conclusions

The conclusions to be drawn from the entire series of experiments fall into three sets: conclusions as to fact, conclusions as to theory and conclusions as to method.

I. The conclusions as to matters of fact have been summarized at the end of the discussion of each group of experiments and need only the briefest review here, since the reader can turn in an instant to the italicized sentences on pp. 122, 135-136 and 143-144. In a few words they are as follows:

a. The chief subject G., who is a predominantly eye-minded person and who projected the color images representing the syllables in a well-defined pattern in the mental field of vision, appears, under normal conditions, to have remembered the series of syllables which were very slowly presented better than those which were presented at a faster rate. This fact is brought out both (1) by the comparison of series relearned respectively at the same slow and fast rates at which they were presented and recited at an unrestricted rate and (2) by the comparison of series learned at different presentation rates but relearned at the same rate and all recited at the rate at which they were presented.

b. There were four other subjects with some degree of training, F., K., C. and D. The results obtained from F. and K. are too few to have much significance. The results of K., who like G. preferred the slow series, appear to be in line with those of G., whereas the results of F., who preferred the fast series, are not. C. and D., who served only in the experiments in which the presentation and recitation rates were the same and in which all series were relearned at the rates at which they were learned, remembered the faster series much better than the slower. D. visualized little, if at all, and C. made little, if any, use of spatial associations.

c. There is much reason to believe that whereas G. learned the slower and faster series (excepting perhaps the *MSP* series) with equally steady and tense attention, C. and D. paid better attention to the more rapidly presented series and had, therefore, linked the syllables of these series by a much stronger set of associations when the first learning was counted complete. The slow rates of recitation in the case of the more slowly presented series may well have concealed a weakness in the associations.

d. In certain rather fragmentary supplementary experiments, the majority of the subjects (who were untrained) appear to have remembered the slowly presented series better than those rapidly presented and there are hints that those who remembered the fast series better found it hard to attend to the slow series.

II. In passing to the theoretical conclusions to be drawn from these facts, the following points should be kept clearly in mind. The *strength* of an association is its *readiness* to function and is measured roughly by the association time, *i.e.*, by the time required for the recalled experience to emerge after the recalling experience comes to mind.[17] The lastingness or wearing-quality or "life" of an association depends (aside from individual differences in retentiveness) upon its initial strength and upon its freedom from retroactive inhibition, *i.e.*, from the dislodging effect of a later formed and very similar association. Its strength at any one time after it is formed and before it is obliterated or renewed must depend upon its initial strength and upon its freedom from retroactive disturbance, and upon the time which has elapsed since its impression. The initial strength of such a series of associations as is formed in learning series of nonsense syllables by the method of complete memorizing may, for our pur-

[17] Aside from the fact that individuals appear to differ in celerity of recall and aside from the fact that the real association time can never be gauged with entire precision, this time is not a perfect measure of the strength of the association, since it may be lengthened by reciprocal inhibition between this association and another. In fact, the strength of an association is best expressed by the probability that it will function sooner or later, a probability which can be gauged by the method of right associates, not indeed for one particular association but for each association as a member of a group formed under certain conditions. See p. 47, note of these Studies.

poses, be reckoned as their strength at the end of the last repetition in the first learning. If the recitation rate is unrestricted and the learner is interested in "doing well" and, therefore, recites as fast as he can, then the recitation time offers a good rough gauge of the initial strength of the associations. But a restricted recitation time cuts out this gauge. A rapid rate of recitation demands pretty strong associations—unless they are helped out by perseveration. A slow rate, if prescribed, may or may not mask weakness in the associations. A rather slow rate of presentation, if *chosen* by the subject in the case of rapidly presented series, must indicate that they are not recited in virtue of the mental echo or, in other words, of perseveration.

We are now ready to restate the main issue and to formulate the main conclusion of this study. Its chief interest lay in determining whether series rapidly repeated (*i.e.*, series quickly presented and recited either at this same quick rate or as fast as the subject chooses) are more quickly forgotten than series learned at a slow rate of repetition. If they are, then it may be inferred that the final recitation was accomplished in virtue of rather weak associations eked out by perseverative (or if one prefer, by *impressional*) tendencies. If they are not, then no tendencies which are in their very nature evanescent can have accomplished a recitation premature in the sense that it took place before the associations were clinched. Now we are forced to conclude that *it cannot possibly be inferred from these experiments both that quickly repeated series are remembered less well than slowly repeated series and also that their poorer retention is due to the fact that in the first learning the final recitation was achieved with the aid of perseveration. For, in the first place, in the only clear and well-substantiated case in which series presented fast were not so well remembered as series presented slowly (that of G. in the first group of experiments), the slow rate of recitation chosen by the subject precludes the possibility that perseveration played a very significant part. And, in the second place, we find that in those cases in which we may be pretty sure that the "mental echo" was present in the case of the rapidly repeated series, they were better remembered than those*

slowly repeated. Thus, the main question of this study is settled in the negative in so far as these experiments can settle it. The reader will realize that the subjects were few and that the fastest rate of presentation and recitation (one syllable to eight-tenths of a second) was really not so very fast, though fairly rapid for the aural presentation of meaningless material.

Two or three questions of minor interest remain. In the first place, we have the task of explaining why G. on the whole remembered the slowly repeated series better than those rapidly repeated and of stressing the reason why this showing was reversed in the cases of C. and D. The answer to the question as to G. is probably as follows: She remembered the slow series better than the fast because slow presentation gave her more leisure for visualizing the spatial patterns in which she imaged the syllables and thus for forming criss-cross associations between them. These associations were less conspicuous in the case of the rapidly presented series, even though the associations between each syllable and the one next following were just as strong. For instance, although the associations between the first and second and between the fourth and fifth syllables were no stronger in the slow series than in the fast, yet the first syllable was more strongly associated with the fifth, which was imaged either beside it or in a corresponding position in the next group of four syllables (really of four color spots). These criss-cross associations (secondary associations intrinsic to the series), like the true mnemonic associations (which are secondary but extrinsic), are revived in relearning and appear to facilitate it. G. made no more mnemonic associations in the slow series than in the fast but she did dwell more on criss-cross connections. G. certainly did not in general pay higher-level or steadier attention to one set of series than to another although, as we have seen, the moderately slow series of the third group of experiments seem to have fared ill at the hands of all the subjects. Rapidly presented series cannot be mastered at all unless the learner strictly attends to business, and the slowly presented series were zealously attended to by G. because she took pride in keeping the number of necessary repetitions as low as possible,

always hoping to make a perfect recitation after a single slow presentation of a twelve-syllable series and sometimes succeeding. On the other hand, C. and D. certainly paid closer attention to the more rapidly repeated series, thus disproportionately reducing the learning time. This fact would not explain the better retention of the rapidly repeated series if we could believe that the associations formed in learning the slow series were in the end equally strong. We have no numerical evidence that they were not, since in the experiments in question the slowly presented series had also to be slowly recited. Since, however, slow recitation was allowed, the series *could* be recited in virtue of weak associations. Since, moreover, C. complained that the slow series were hard to attend to and since D., throughout the experiments exerted herself as little as possible, we have much reason for supposing that the initial strength of the associations in the slow series was actually low. Superiority in the initial strength of the primary intrinsic or "intentional" associations (the associations between each syllable and the one next following) probably then explains the better retention of the quickly repeated series by these two subjects. This conclusion is, of course, in direct contradiction to the supposition which gave rise to this study.

In the second place, it must be frankly confessed that the experiments *fail to give the slightest indication of any physiological advantage in slow repetition—of any consolidation process as involved by it.* The advantage of the slow series in the case of G. is sufficiently explained by her peculiar method of memorizing. On the other hand, in the cases of C. and D., the disadvantage of slow repetition, namely, its failure to enforce steady attention, was great enough to *hide* a considerable physiological advantage.

Finally, it must be said that the explanation of the feeling of automatism which one has in reciting a rapidly and frequently presented and recited series must remain an open question. The series—often rather suddenly—rolls out before the mental eye or reels off in internal or actual speech as if the reciter were a mere reader or mouth-piece. This sort of thing does not seem

to happen in the case of slowly repeated series. Why? One can scarcely explain it as a vocal-motor automatism because speech, whether internal or actual, is not always prominent in this self-thrusting of the series into consciousness. There are two possible explanations of the experience. (1) It may be that the associations, very strong because they are very fresh and repeatedly stamped, function so quickly that the learner suffers a slight emotional shock. (2) It may be that the mental echo is really a perseveration of the members, a perseveration forced into serial order by the associations between them. (*Cf.* p 108 above.) The question reduces itself to this: Are "impressional tendencies" more important in this phenomenon than in ordinary recall? If so, they produce all that the present writer means by perseveration. *These experiments show that such perseveration, if it exists, is less important in the recall of rapidly repeated series than the writer had supposed, but they do not explain away the feeling of suffering, or being passive under, the intrusion of the series members.*

III. The conclusions as to method the writer believes to be the only important contribution made by this study. Although she has clearly seen how her method might be improved, she has never made any more retention experiments of this type. At the end of this study, she had become completely discouraged in the attempt to make such experiments with undergraduate co-operation. Under the conditions of undergraduate life and work, it is absolutely impossible to secure the learning and relearning of a large number of series, under parallel conditions, by a satisfactory number of subjects. If, however, one has the temerity to make experiments similar to those described in this paper, the following points should be noted:

a. Parallel experiments should be made with a restricted and with an unrestricted recitation rate. An unrestricted rate is likely to have a dangerous effect upon attention unless the subject is taking a keen and unflagging interest in his work. On the other hand, the restriction of the recitation rate withdraws the invaluable gauge of the initial strength of the associations

which is furnished by the recitation times, if the subject is allowed to recite the syllables without nervous haste and yet as fast as they occur to him.

b. Even if the recitation rate is to be restricted, slow recitation should not be required. In other words, the subject should be required to recite the slow series not at the rate at which they were presented but at the rate at which he recites the fast series. At first, a certain emotional disturbance is involved in passing from slow presentation to fast recitation, but this soon wears off. (This the writer knows by experience as subject in work which is not yet ready for publication.) If the series are all recited at the same rate, one can, of course, compare, as regards firmness of associations, only the effects of slow and of fast presentation and not the effects of the slow and fast traversing of the whole series, the part recited as well as the part presented. The first comparison, however,—that is, the comparison of presentation rates—is simpler and needs to be made before the more complicated comparison is attempted. In any case, the artificial lengthening of intervals in recitation permits and conceals the recitation of the series in virtue of weak and lagging associations, allows the attention of some subjects to wander, and tempts others to fill up the pauses by inventing far-fetched mnemonic connections or by making private reviews of parts of the series, reviews which are not counted in the numbers of repetitions which the experimenter guilelessly sets down in his record-book.

c. Of the two methods of gauging retention described in the section on method, the second is greatly preferable. That is, it is better to compare the ease with which series, learned at different rates, are relearned all at the same rate than to compare the fractions of work saved when series, learned at different rates, are relearned at the rates at which they were, respectively, learned. The objections to the latter method are perhaps three. The two certain objections have already been mentioned. In the first place, if the rate of recitation is restricted, the subject is as likely to be frightened in relearning as in learning and his fortuitous break-downs in relearning obscure the residual difference

between the numbers of necessary repetitions and learning times. (For illustration, see p. 116.) In the second place, if the average number of repetitions is accidentally high in the first learning, as it is likely to be if the subject has difficulty in reading or in "hearing" unfamiliar syllables, then the percentage of work saved in relearning these same syllables, now more familiar, exaggerates the firmness of the associations formed in learning. If, on the other hand, the number of repetitions necessary to the first learning is approaching unity (as when G. was learning slowly repeated series of twelve syllables), it is numerically impossible that the saving in repetitions should be large. Lastly, it is at least possible that series learned and relearned at a slow repetition rate might appear to be better (or worse) remembered than series learned and relearned at a fast rate, not because they were *learned* at a slow rate but because they were *relearned* at a slow rate. In other words, if two sets of series were learned at the same rate but relearned at the different rates, those relearned at the slower rate might appear to be better (or worse) remembered than those relearned at the faster rate. It is very possible that one repetition rate more than another favours the revival of associations equally moribund when the relearning commences. In our experiments there is evidence neither for nor against this supposition, but if there be any truth in it, then, in a test of relative firmness of associations, series learned at different rates should be relearned at the same rate.

In conclusion, the writer wishes some one else joy in making similar experiments under conditions more favorable than she has been able to secure.

II

The Relative Amounts of Fatigue Involved in Memorizing by Slow and by Rapid Repetition

BY

JOSEPHINE NASH CURTIS

With the Assistance of Helen K. Goss and Ethel Caution-Davis

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Editor's Note

This paper contains the substance of a thesis which was presented by Josephine Nash Curtis in the June of 1912 to the Academic Council of Wellesley College in partial fulfilment of the requirements for the degree of master of arts. The outcome of the experiments was such as to justify the publication of the thesis only in a greatly abridged form. The work of cutting the text and of making shorter tables has been done by the editor with material assistance from Miss Goss. The editor has rewritten the conclusions *ex radice*.

II.

THE RELATIVE AMOUNTS OF FATIGUE INVOLVED IN MEMORIZING BY SLOW AND BY RAPID REPETITION

Introduction

In looking over the literature of experimental work in psychology, one can hardly help noticing with surprise how few of the many and detailed memory investigations have aimed primarily to discover the effect of the rate of repetition of the material to be memorized upon the difficulty of memorizing, whether this difficulty be measured by the number of repetitions or by fatigue. The general purport of such work as has been done is to show that a rapid rate increases the number of repetitions necessary for complete mastery, but decreases the total learning time; in other words, that, whereas each slow repetition accomplishes absolutely more, if considered with reference to the amount learned per repetition, each fast repetition accomplishes relatively more if viewed with reference to the amount learned per unit of time.[1]

The object of this paper is to present a comparison of the fatigue effects of memorizing normal series of nonsense syllables by slow and by rapid repetition. The question in regard to fatigue is two-fold: (1) Is fatigue more apparent when the subject memorizes by rapid repetition than when he memorizes by slow repetition? (2) If so, is the fatigue of memorizing at a rapid repetition rate so great as to cancel the time-saving effect of rapid repetition within the limits of a laboratory appointment lasting three quarters of an hour? A question of minor importance concerns the limit at which decreasing the rate of presentation decreases the number of repetitions necessary for

[1] See Ogden, *Untersuchungen über den Einfluss der Geschwindigkeit des lauten Lesens auf das Erlernen und Behalten von sinnlosen und sinnvollen Stoffen,* Arch. f. d. ges. Psychol. 2 (1903), pp. 163 f.; Ephrussi, *Experimentelle Beiträge zur Lehre vom Gedächtnis,* Zeitschrift f. Psych. und Physiol. der Sinnesorgane, 37 (1905), pp. 183 f.; and Ebbinghaus, *Grundzüge der Psychologie,* zweite Aufgabe, pp. 671 f. *Cf.* also Jacobs, *Ueber das Lernen mit äusserer Localization,* Zeitschrift f. Psych. und Physiol. der Sinnesorgane, 45 (1907), pp. 66 f.

memorizing and the limit at which increasing the rate of presentation diminishes the learning time. Ephrussi raised this question but gave a merely speculative answer.

To answer the first of the two questions primarily at issue, *viz.*, the question as to whether or not fatigue is more apparent when the subject memorizes by rapid repetition, one must solve the difficult problem of finding a simple yet efficient measure of fatigue. So many factors enter into fatigue that it is practically impossible to isolate one and test it, and it seems still more useless to attempt to find one test that measures all the factors at once. Then, too, individuals apparently differ to a great extent, both in the amount of work it takes to fatigue them and in the way in which fatigue affects them. The experimental study in fatigue is further seriously complicated by the methods employed by different experimenters in using the same test. This, indeed, sometimes makes it impossible to compare the results of different investigators. Tests of mental fatigue may be grouped in two ways: in the first place, as physical or mental; in the second place, as extrinsic or intrinsic. In the intrinsic test, fatigue is measured by the speed and accuracy with which the subject performs the same work that has fatigued him; in the extrinsic test, the fatigue is measured by his comparative efficiency in another kind of work. The extrinsic tests actually employed in this investigation were selected rather for their simplicity and variety than because of any unanimity in the conclusions of those experimenters who have used them. Of these the only physical test was with the dynamometer. The mental tests were: reaction time, and speed and accuracy in doing arithmetic.[2]

Subjects, Materials and Methods

The subjects used in these experiments were seven in number,—Miss Gamble, "G."; Miss Agnes Rockwell, "R."; Miss Florence Banks, "B."; Miss Cecilia Hollingsworth, "H."; Miss Evelyn Keller, "K."; Miss Marjorie Sawyer, "S."; and Miss Nathalie Williams, "W." All began work in October, 1911,

[2] For a brief bibliography, including titles of experimental studies of fatigue, see pp. 189-190 below.

except S., who was put in after the Christmas vacation to take the place of a subject whose results proved so erratic as to be absolutely useless for our purpose.

The only subject who had had much experience in such work was G., who was the principal subject of the earlier memorizing experiments in this laboratory.[3] In our work she served as subject two periods each week. It should be noted that in this paper the length of a period, unless otherwise stated, is to be understood as forty-five minutes. In Groups I and II of the following experiments, G.'s periods fell on different days; in Group III they were consecutive. Subjects H., K., and S. were all Wellesley College seniors taking a second course in experimental psychology; W., a junior taking the same course; and B., a senior who had had only one course in experimental psychology. All these subjects served one period a week for the year, except S., whose late beginning has already been mentioned. R., who acted as subject one period a week in Groups I and II and two periods a week (on different days) in Group III, was a senior taking the same second-year course.

In these experiments we used series of twelve nonsense syllables made in imitation of the normal series of nonsense syllables devised by Müller and his collaborators. These series are discussed briefly on page 110 of the preceding paper.

All the series were aurally presented and were learned by the method of complete memorizing. The rate at which a series was presented and recited was regulated by a metronome. The experimenter said "Now" on one beat of the metronome, waited a beat, and then began to present the series. In some experiments, the syllables were given on every beat, in others on every other beat, and in still others on every third beat. When the experimenter had finished reading the series, she waited a beat and on the next beat said "Now." The subject was then expected to repeat the series from the beginning, starting on the next beat but one, after the experimenter's "Now," and saying the syllables at the same rate at which they had been presented. If the subject failed to give a syllable on the proper beat of the metronome,

[3] See pp. 82 f., 119 and 122 f.

the experimenter gave that syllable on the next beat and then presented the remaining part of the series at the prescribed rate. If the subject gave a wrong syllable on any beat, the experimenter interrupted her on the next beat with the correct syllable, accenting it strongly to impress the subject with the fact that she had given a wrong syllable. The experimenter then finished the series, waited a beat, and said "Now" as in the first presentation. Once more the subject tried to recite the series from the beginning and was, if necessary, prompted or corrected by the experimenter as before. This procedure continued until the subject succeeded in repeating the whole series correctly and on the proper beats of the metronome. The experimenter who read the series to the subject also kept the record of her attempts at reproduction by making columns of characters beside the series, each column corresponding to an attempt of the subject.

Thus, by counting the columns of signs, we knew the number of repetitions necessary for complete mastery, and the characters enabled us to tell at what point in each repetition the subject broke off, and the nature of the failure. An assistant experimenter kept the time, starting the stop-watch at the reader's "Now" and stopping it on the subject's completing a perfect recitation (that is, a recitation correct and given at the proper rate) of the series. This second experimenter also kept the records of the fatigue tests.

Inasmuch as the point at issue was simply to discover which rate of repetition was more fatiguing, it was necessary to eliminate in the two sets of experiments (with slow and with rapid repetition) all differences other than rate which might possibly occasion differences in fatigue. The length of time required for learning a series is possibly an important factor. If, for example, it takes twice as long to learn a slow series as to learn a fast, and if the subject shows more signs of fatigue at the end of the slow, it would be impossible to say how much of the fatigue is due solely to the rate and how much to the fact that the subject's attention has been kept on a stretch for a longer time. It would also be impossible to say whether the results in the case of the "slow" series are influenced through genuine fatigue or merely through ennui. In order to eliminate as far

as possible these difficulties, we endeavored to find two rates of repetition, one fast and one slow, which required approximately the same learning time. This proved not to be difficult, for we found from a few skirmishing experiments with all the subjects that as we increased the rate of repetition from very slow to very fast, the total learning time grew shorter and then again longer. It is evident, of course, that if one finds that a series given slowly takes no longer than a series given rapidly, it must be because the fast series is repeated too fast to save time. The question regarding the point at which increasing rate of repetition ceases to economize time is, it will be remembered, one of the secondary considerations of this study.

Our experiments fall naturally into three groups. In Group I, the preliminary experiments, the purpose was to discover at what two rates the subjects had about the same total learning time. In these we first gave the subjects series, as already described, at the rates 60/100, 60/75, 60/60, 60/30, 60/20 and 60/15. This method of differentiating between rates shows the relationship between the seconds occupied in giving a certain number of syllables and the number of syllables given, the numerator showing the former and the denominator the latter. For example, the rate 60/100 means that at this rate one hundred syllables would be presented in sixty seconds or, in other words, that the twelve syllables were actually presented at the rate of one syllable to every 6/10 of a second. We soon abandoned the 60/100 and 60/15 rates, as we found that the rate 60/100 was obviously too fast to economize time and that the rate 60/15 was obviously too slow to economize the number of repetitions. The sets of rates finally chosen for the different subjects were as follows:

G. 60/60 — 60/20
R. 60/75 — 60/20
B. 60/60 — 60/20
H. 60/60 — 60/30
K. 60/75 — 60/30
S. 60/75 — 60/30
W. 60/75 — 60/30

As will be seen later, the success of this plan was somewhat impaired by the fact that some of the subjects seemed to be affected at one rate by practice much more than at others.

When the rates to be used were finally determined, Groups II and III of the experiments were performed. In Group II, a number of fatigue tests were made at the beginning of the period, and were interpolated after the memorizing of every two series.[4] The experiments of Group III differed from those of Group II in the facts (1) that only one extrinsic test of fatigue was used, and (2) that a greater number of series were learned at each sitting, and that the subject's gradual loss of efficiency in memorizing was regarded as the chief index of fatigue. In these two groups, all the series presented in one day were given at the same rate. The rate to be used each day was determined according to a compensating program in order to prevent, as far as possible, series given at either rate from having the advantages of practice more than series given at the other rate.

We have outlined our procedure in performing the memory experiments and have differentiated between the three groups into which the experiments fell. We come now to the consideration of the fatigue tests. The results of all previous attempts to measure fatigue have proved so very contradictory that we decided, as already noted, to choose as many and varied extrinsic tests as seemed practicable in consideration of the time and apparatus at our disposal. The tests employed, for a longer or shorter period, were: (1) tests of muscular strength made with two different dynamometers; (2) tactile-reaction time; (3) auditory-reaction time; (4) free-association time; (5) a test of appreciation for rhythm made with a telegraph key, an electric

[4] At the very first, we introduced the tests after every series learned. However, we soon abandoned this procedure as we found that the tests often occupied more time than the learning of the single series, so that the fatigue at the end of a period might be due more to the tests themselves than to the memorizing. Of course, the tests in question, when made at the beginning of the period were not, properly speaking, fatigue tests at all but merely tests of normal efficiency.

pen and a kymograph; (6) a test of the delicate muscular co-ordination involved in needle-threading; (7) tests of speed and accuracy in arithmetical calculation. Tests 5 and 6 were speedily abandoned on account of glaring inconsistencies in the results. The arithmetic tests are the only extraneous tests which proved at all satisfactory. The procedure in the various tests was as follows:

The dynamometer.—In this test we used at first a piece of apparatus, consisting primarily of a suspended spring balance, described by Titchener in his "Experimental Psychology, Student's Manual, Qualitative," 1899, page 100, and manufactured by Stoelting and Co. This dynamometer proved useless, for even after limiting the performance so as to require the subject to keep the handle between the second and third joints of her fingers and to keep her feet off the floor (to prevent additional leverage from bracing), we found it impossible to be sure that the subject was using the same set of muscles all the time. The second dynamometer used was one of the elliptical-grip order, manufactured by Thomas A. Upham of Boston. With this instrument the subject was required to use only her right hand and to squeeze as hard as possible, and she was not allowed to stand in making the test.

Tactile-reaction time.—In this test we used Sanford's vernier chronoscope as manufactured by Stoelting.

Sound-reaction time.—Again we used the vernier chronoscope making the auditory signal by rapping sharply on the releasing key with a piece of wood. We made no specification in either of these experiments as to whether the reaction was to be sensorial or muscular.

Free-association time.—This we measured by a Hipp chronoscope connected in circuit with a fall-screen and a lip-key in such a way that when the screen fell, exposing the stimulus word on an upright tablet behind the screen, the circuit was broken and the chronoscope started. As soon as the subject dropped the lip-key by giving the reaction word, the circuit was made and the chronoscope stopped. The subject G. had difficulty in reading the words at the distance at which it was neces-

sary to expose them and therefore had to have her stimulus words auditory instead of visual. In order to prevent the necessity of rearranging the apparatus for auditory stimuli the experimenter dropped the screen at the same time that she spoke the word. The stimulus words were all one-syllable nouns and only names of visible things were used. The reaction word of the subject was not recorded.

Appreciation of rhythm.—It was suggested at the beginning of these experiments that inasmuch as some authors[5] claim that the cause of many factory accidents is the loss of the appreciation of rhythm by the employees, it might be interesting to find whether mental fatigue would bring about any loss in appreciation of rhythm. To test this we required the subject to tap on a telegraph-key connected with a magnet pen which, as the key made and broke the electric circuit, traced a zigzag line on a kymograph. The subject was required to strike the key on certain metronome beats in a somewhat complicated rhythm which she was required to read into the beats of the instrument set at the rate 60/100. The results of the experiment, however, were absolutely negative, *i.e.*, no subject failed at any time to tap at exactly the right moments; and, therefore, no mention will be made of this test in the discussion of results.

Speed and accuracy in arithmetical calculation.—The first test was in addition of columns of the ten digits arranged by chance. The subject was required to add as far up a column as she could, in thirty seconds, with certainty of correctness. A record was kept of the number of digits added, the sum obtained, and the correctness of the answer. The second arithmetical test, used only in Group III and the only extraneous test in this period, was in the multiplication of the ten digits arranged by chance to form two five-place numbers. The subject was required to multiply the numbers as rapidly as possible with certainty of correctness, and a record was kept of the time taken and also of any mis-

[5] Bogardus, E. S. *The Relation of Fatigue to Industrial Accidents,* Am. Jour. of Sociol., 17, pp. 220-222; Brandeis, L. D., *Women in Industry,* Decision of the United States Supreme Court in Curt Muller vs. State of Oregon, Reprinted for the National Consumers' League.

takes made. The multiplication test was not introduced in Group III after every two series, as were the tests in Group II, but only three or four times in a period.

Our experimental procedure has now been described. The methods used in the calculation of all the results of this investigation were as follows: Results of any one kind for different days of the experimental group were recorded in horizontal lines placed under each other so that the corresponding figures for any given task on all the different days could be readily added and averaged. For example, the numbers of repetitions required by G. for learning the first series given on each day were written in a vertical column; the figures for the second series were written in another vertical column; the figures for the first addition test were written in still another column, and so on. The tables and other numerical statements given in the next section are self-explanatory, except for the use of percentages. The extrinsic fatigue tests varied so much in units of measurement that it was necessary to find some common measure, if the figures for the different tests were to be properly compared. We finally decided upon the following procedure: The first performance of any given kind on each day, *e.g.,* the time taken for a tactile reaction before any memorizing had been done, was taken as the normal performance of its kind and was treated as unity. We next found the percentages of the first result that the figures obtained upon each of the succeeding trials represented. By this method we had all our results in the same terms (*i.e.,* percentages) and were able to compare the changes arising in the results of the various tests.

In most of the tests the results of all the subjects have been averaged together, as well as for each individual, and the results of all the subjects except G. and K. have also been massed apart from the results of these two subjects. The latter procedure seemed admissible in view of the fact that the results of B., H., R., and W. showed about the same trend. The results of G. and K. diverged decidedly and could not be included without obliterating all the significance of the averages.

Numerical Results

In this section the results of the extraneous tests and the signs of fatigue displayed by the changes in the numbers of repetitions necessary for learning the series will be considered. The results of Group II and of Group III will be discussed together as far as possible, since these groups, as will be remembered, differed not in general method or aim, but merely in the extraneous tests used and in the number of series learned in a period. The tentative nature of the first group of experiments has already been stated; the results for each of the many rates employed were few and need no further discussion here.

I. *Extraneous Tests*

Dynamometer tests.—Tests made with the spring-balance dynamometer (Stoelting's) proved entirely unsatisfactory on account of the different sets of muscles brought into play by the same subjects in different trials. Tests made with an elliptical-grip dynamometer showed for the principal subject G. no consistent change in muscular strength during the process of memorizing. The tests were therefore abandoned at so early a date that the results for the other subjects are too few to be discussed seriously.

Tests of reaction time.—The figures for auditory and for free-association reaction time are extremely inconsistent for each individual subject and have therefore been entirely discarded. The results of the tests of tactile-reaction time are parallel to those of the test with the elliptical-grip dynamometer: the subject G. showed no consistent increase or decrease of reaction time when memorizing either with fast or with slow repetition. The results for the other subjects are too few to be presented in detail. It should be noted, also, in regard both to the dynamometer and to the tactile reaction time experiment that the results for G. (in so far as they show anything) and the results for the other subjects (as far as they go) are in direct contradiction to one another. These results, therefore, have also been set aside.

Arithmetic tests.—In the addition test the results had to be

calculated in a manner somewhat more complicated than that of the other tests, for we had to take into account not only the number of digits added in the given time but also the sum obtained. This was necessary because it is of course harder to add a number of large digits than the same number of small ones, and if the majority of the digits in a certain column happened to be large, the subject would not be able to add as many as if they had been small, but the sum obtained would be larger. The number of figures added and the sums obtained were added separately; the resulting sums for the different trials were then represented by percentage in the manner described on p. 165, the first percentage of each kind being treated as unity; the two sets of percentages were then averaged and the final average percentages are those taken into consideration. The results of G. diverge greatly from those of the other subjects. In memorizing by fast repetition she shows a steady decrease in the amount of work done, supplemented by a final spurt at the end. In the fourth addition test on each day (the test given after six series had been memorized) her efficiency is only 81% of her average efficiency at the beginning of a sitting. A terminal spurt is manifested in the rise of her efficiency to 88% in the fifth and last addition test. In memorizing with the slow series G. shows practically no change in ability to do addition. R.'s later efficiency percentages are always smaller than her normal and, on the whole, show more deterioration through memorizing by slow repetition. B. shows a steady decrease in amount of work done after the "slow" series and a very decided increase, falling off somewhat at the end, after the "fast." In the fourth of the addition tests, given in the course of memorizing by slow repetition, her efficiency percentage is only 69. In the third of the tests given in the course of memorizing by fast repetition, the percentage rises to 126 dropping to 106 on the fourth and last test. The averages obtained from the results of all the subjects, including G. and K., are worth little, showing merely that the subject's efficiency is never as great in the later trials as in the first, but exhibiting no difference between the results obtained in the course of memorizing with slow repetition and those ob-

tained in the course of memorizing with fast, and showing no progressive change in efficiency in either set of experiments. If, however, the results of G. and K. be excluded from the averages it would seem that ability to add always deteriorates in the case of the slow series while in the case of the fast series it at first increases slightly and then decreases slightly. In the case of these tests, unlike the last two sets or reaction-time experiments, it is admissible to average the results of R., B., H., and W., for all show the same general trend. With one exception (H.) more mistakes were made in the arithmetic when the subjects were memorizing at the slower rate.

The multiplication test was the only extraneous test used in the third group of experiments whereas the addition test was one of a number used in Group II. The use of the multiplication in place of the addition test has the following advantages: (1) Closer concentration is secured; (2) the setting of a relatively difficult example in multiplication demands less space than the setting of a sum in addition. On account of this second circumstance, the figures could be written larger and variations between subjects due to differences in ease in reading the numbers could be avoided. In the multiplication tests we improved upon our procedure in the addition tests by measuring the time required for performing the task set instead of measuring the amount of work done in a given time.[6]

The multiplication test gives, in general, results which differ at many points from those obtained from the addition test. G.'s results show decrease in speed of multiplying after memorizing with rapid repetition and an alternation, probably accidental, between decrease and increase in speed after memorizing with slow repetition. Thus, G.'s results in the multiplication test fall fairly well into line with her results in the addition test. This assertion, however, cannot be made for all the other subjects. For example, R., who in the addition test lost efficiency in the case of both the fast and slow series, here in the multiplication test loses in efficiency in the fast series but gains in the slow, and B.,

[6] Thorndike, E. L., *An Introduction to the Theory of Mental and Social Measurements,* p. 14.

who in the addition test lost in the slow and gained in the fast, here, in the multiplication test, gains in both. In the multiplication tests the results of B., H., S., and W. are all fairly consistent with one another and show a gain in efficiency with both the fast and the slow series. K. is, as usual, at variance with the other subjects and shows marked deterioration in the case of both slow and fast series. Thus, the figures from the two kinds of arithmetical tests taken in combination show little or nothing in regard to the fatigue-effects of the two rates of memorizing. G.'s results alone are consistent and, as we shall see, G. is probably the only subject (except perhaps K.) who suffered real fatigue. In the case of the other subjects, the variations are undoubtedly accidental.

The proportions of the total number of examples, done by all the subjects in a period, which show mistakes are as follows:

Slow		*Fast*	
Example I,	9%	Example I,	24%
II,	22%	II,	24%
III,	11%	III,	33%
IV,	8%	IV,	33%

That is, in general there were many more mistakes with the fast rate than with the slow. During the course of the experimental period with the slow series, the number of mistakes increases suddenly and then in the last trial decreases slightly; with the fast series, the number of mistakes made increases slightly. The discrepancies in the results of the extraneous tests are discouraging in view of the fact that the subject G., whose results are more numerous by far than those of any other subject, persistently differs from the other subjects in so far as the latter exhibit any common trend. It was exactly on account of the equivocal results furnished by the extraneous tests in Group II, that the only extraneous test used in Group III was the multiplication test just described. It is to be regretted, however, that the method of extraneous tests was not entirely abandoned, since, as will later appear, the best gauge of fatigue was the gradual deterioration of efficiency in memorizing, and since the interpolation of even one extraneous test gave the subject a change of occupation, arrested fatigue, and hampered us in the use of this intrinsic criterion.

II. *The Intrinsic Test*

The intrinsic criterion of fatigue is the change in the number of repetitions necessary for memorizing. The more important results of the investigation are presented in Tables 1 and 2. Table 1 exhibits, for the subject G., the numbers of repetitions necessary to learn the series arranged according to their time-position on the different days. Table 2 covers the corresponding results for the other subjects. Each one of these tables contains results from both the second and the third groups of experiments. The abbreviations *s* and *f* as used in the headings of both tables stand respectively for the "slow" and "fast" rates of repetition compared. The numerals in parenthesis after the *s* and *f* stand for the numbers of series represented in the averages.

As recorded in the tables, the results of all the tests seem meagre. It must be remembered, however, that the results have been separated according to their position in the series of tests made on each day (*Zeitlage*) and that, therefore, although really a great many experiments were made, there are but few results of any one kind. The most striking example of this is the work of the subject G. in Group III. G. learned 192 series of nonsense syllables, but the number of series learned at each rate and time-position is only 4. The results of subject G. (found in Table 1), and of R. and B. (found in Table 2) are the most noteworthy because G. and R. had had practice in working with nonsense syllables and so had no difficulty in apprehending them, and because the results obtained from these three subjects are more numerous than the results of H., K., and W. In Group 2, the results of the subjects, taken individually, are inconclusive. G.'s efficiency clearly deteriorated in the course of the period but not uniformly and not at one rate more than at the other. If a few scattering results obtained from R. on days when she happened to learn more series than usual be discarded, it is evident that the subject's ability to learn decreases rather steadily during the course of the day's experiments, with slow repetition, whereas with fast there is at times a slight improvement and at others a deterioration. R.'s loss of efficiency, however, is never as great with the fast series as it is with the slow. B. shows no loss of

TABLE 1

Subject, *G*

Group II			Group III											
Series	s (13)	f (12)	Series	s (4)	f (4)	Series	s (4)	f (4)	Series	s (4)	f (4)	Series	s (4)	f (4)
1	1.9	4.1	1	1.8	4.5	7	1.5	5.3	13	2.3	4.8	19	1.8	7.3
2	2.6	5.7	2	1.8	5.0	8	3.0	4.5	14	2.3	5.8	20	2.0	6.8
3	2.2	5.4	3	2.5	6.0	9	2.0	4.0	15	2.3	6.8	21	2.3	6.5
4	2.7	5.4	4	2.5	5.3	10	2.5	5.8	16	2.8	8.5	22	2.5	6.5
5	2.5	5.3	5	3.0	6.0	11	3.3	6.0	17	3.0	5.3	23	3.0	4.8
6	2.6	6.6	6	2.5	5.3	12	2.8	6.3	18	2.3	7.0	24	2.8	5.0
7	2.9	4.3												
8	2.4	6.6												
Average				2.3	5.3		2.5	5.3		2.4	6.3		2.4	6.1

efficiency during the period, but on the contrary an increase with both rates. This increase is greater with the slowly repeated series. The results of H., W., and K. are too meagre to receive more than passing comment. H. shows deterioration during the period with the slow series and, at first, improvement and then deterioration with the fast. W. shows improvement with the slow and deterioration with the fast. K.'s second trial shows, with the slow, an increase in the number of necessary repetitions; with the fast, a decrease. K.'s results for later trials show improvement to about the same degree for both rates. When the results of the subjects are averaged (whether with or without G. and K.) they seem to show that the subject's ability to memorize improves from the beginning of the period with the slow series, while, with the exception of a terminal spurt, it grows less with the fast series. No importance, however, may be attached to this seemingly definite result, for it is evident from Tables 1 and 2 that with such great individual differences an average is meaningless.

It will be remembered that in the experiments of Group II, a number of fatigue tests were interpolated after the memorizing of every second series. This fact justifies the suspicion that a or most of the subjects were spared real fatigue by the change of occupation. In the experiments of Group III, which have now to be considered, larger numbers of series were memorized without the interruption of a fatigue test. The multiplication test when it occurs, divided the series into groups.

In Group III, in considering the variations in the number of repetitions necessary for memorizing the series, the results will be treated first just as those from Group II were treated, and then afterwards, changes grosser than those from one single series to another, *i.e.*, changes from one set of series learned between two multiplication tests to another such set, will be discussed. The subject G., who was working a double period, learned twenty-four series a day. The number of series learned between the interpolated tests was six. This division into sets is plainly shown in Table 1 and the numbers of series in each set are averaged separately. In the case of the other subjects, the multipli-

TABLE 2

Subjects		R.		B.		H.		W.		K.		K New method		S.	
	Series	s (5)	f (5)	s (4)	f (3)	s (1)	f (1)	s (2)	f (2)	s (2)	f (2)				
Group II	1	4.2	12.4	5.5	9.0	9.0	14.0	16.5	9.0	10.5	20.5				
	2	5.4	12.2	4.3	9.0	9.0	9.0	6.5	22.5	12.5	10.5				
	3	6.8	13.2	4.0	7.7	10.0	13.0	7.5	14.5	11.5	22.5				
	4	4.8	15.2	3.3	8.0	11.0	15.0	15.0	30.5		22.5				
	5		11.4	4.5	8.7	10.0	25.0		12.5						
	6			4.8	8.7	14.0	12.0		19.5						
	Series	s (8)	f (8)	s (4)	f (4)	s (5)	f (5)	s (4)	f (4)	s (4)	f (4)	s (2)	f (2)	s (4)	f (4)
Group III	1	3.3	10.1	3.5	7.5	6.6	11.2	8.5	13.8	9.8	20.5	10.5	15.7	3.8	8.8
	2	3.9	11.3	3.5	7.5	6.8	10.8	7.8	12.0	7.8	17.8	5.5	16.7	5.8	12.5
	3	4.0	12.3	3.3	7.0	7.6	13.2	6.8	12.8	8.0	16.5	5.0	16.0	6.0	14.3
	4	4.1	10.5	2.8	7.5	8.0	15.2	6.3	13.3	8.8	26.8	8.5	19.3	4.8	10.5
	5	3.9	11.1	3.0	6.0	9.4	13.8	6.5	12.3	8.0	16.3	8.0	16.3	6.0	12.3
	6	3.9	9.9	4.0	7.0	9.6	14.8	8.5	13.3	13.0	15.0	13.0	15.0	5.5	14.0
	7	4.5	11.4	3.5	7.5	7.2	12.4	6.0	13.8					5.3	12.0
	8	4.3	10.4	3.5	7.0	8.2	13.2	7.8	13.8					5.5	12.8
	9	4.9	11.0	3.0	7.0									4.8	11.0
	10	4.0	10.8	4.7	7.7									6.3	11.5
	11			3.0	8.0									5.8	16.5
	12			4.5	7.3									6.8	11.0

cation tests divided the series memorized into halves or thirds. This division could not be shown in Table 2 but is indicated below in the text.

Treated by the first method, G.'s results are inconclusive. With two exceptions (series 7 in the slow set and series 9 in the fast), this subject on the average never learns any of the later series in the period in fewer repetitions than she needed for the first series. Her ability to memorize, however, does not deteriorate in any regular way. For the first fourteen series learned in a day greater deterioration is shown, in general, with the slowly repeated series, whereas for the last ten of a day's series greater deterioration is shown, in general, with the rapidly repeated series. The subject's explanation of the figures will be given in the paragraphs devoted to introspection.[7] R.'s results are apparently more positive. With one exception (series 6 in the fast set) her results show that the first series of a day is learned with fewer repetitions than are any of the succeeding series. The loss of ability to memorize, however, is always greater, for the slow series than for the fast. B.'s results show that her efficiency increases at first with both rates and decreases at the last with both rates. Much greater variations from the average number of repetitions required for learning the first series are shown in the slowly repeated series than in those repeated rapidly. H.'s results for both rates, except for a slight improvement in series 2 of the fast set, show deterioration during the course of a period's memorizing. This subject, however, shows practically no difference between the effects produced by the two rates, for both show a great loss of ability about the middle of the period and a final spurt at the end. H.'s slow series give results which are slightly more variable than those of her fast series. W.'s results show, with two slight exceptions, improvement during the course of a day's experiments. Her results for the slow series are much more variable than her results for the fast, and the improvement in ability to memorize is much more marked with the slow series. K.'s results, as first calculated, are inconclusive. The subject, however, changed her

[7] *Cf.* pp. 31-32.

method of memorizing during the course of the experiments, and, if the results obtained under this new method alone be considered, we find a very decided improvement during the period, except for the last series with the fast rate. The results for the slowly repeated series are much more variable than those for the series rapidly repeated. The results of S. show with both rates an increase, during the period, in the number of repetitions necessary, or, in other words, a decrease in ability. In general this change is more marked with the slow series but the difference is slight.

From the comparisons just made we gain very few conclusions. The most important is that with nearly all the subjects the results for the slow series reach values which differ more from the normal than the values for the fast series differ. The results for the different subjects may be contrasted as follows: G., B., and H. show no decided difference in the effects of the two rates, although B. improves with both rates and G. and H. deteriorate with both. R. and S. show greater deterioration with the slow rate though they also lose in efficiency with the fast. W. shows greater improvement with the slow rate though some improvement with both. K., like B., improves about equally with both rates except for a drop at the very end of the period when memorizing at the fast rate.

The results of Group III will now be treated by the second of the two methods mentioned above, the massing method. In order to compare the changes in efficiency caused by memorizing at the different rates, by larger steps than from series to series, the results of all the series which any subject learned between two successive multiplication tests have been averaged together and treated like the results of one series. This method of treatment gives the general trend of a period's work and avoids the confusion introduced by the more accidental variations in the individual series. It is unfortunate that the space available in Table 2 did not permit us to indicate the divisions for the subjects other than G. or to interpolate the group averages in the fashion in which the divisions and averages have been given for G. in Table 1. For the subject R. the size of

the group is five; for B., four; for H., four; for W., four; for K., three; and for S., four. The group averages in order are: for R., in the slow series, 3.8 and 4.3, and in the fast series, 11.1 and 10.7; for B., in the slow, 3.4, 3.5 and 3.8, and in the fast, 7.4, 6.9 and 7.5; for H., in the slow, 7.3 and 8.6, and in the fast, 12.6 and 13.6; for W., in the slow, 7.4 and 7.2, and in the fast, 13 and 13.3; for K., in the slow, 8.5 and 9.9, and in the fast, 18.3 and 19.4; for K. with her "new method," in the slow, 8, 6.8 and 10.5, and in the fast, 16.2, 17.7 and 15.7; for S., in the slow, 5.1, 6.6 and 5.9, and in the fast, 11.5, 12.8 and 12.5. When massed in this manner, G.'s results show deterioration with the slow rate, becoming less marked as the period advances, and with the fast, at first practically no change and then great deterioration. R. shows a decided loss of ability with the slow series, a slight gain with the fast. B. shows steady deterioration with the slow rate, and with the fast, at first an improvement and later, a condition nearly normal. H. shows deterioration with both rates, but this is more marked with the slow. W. shows a slight gain in ability with the slowly repeated series, a slight loss with those rapidly repeated. K.'s results (if those obtained with the new method only be considered) show at first improvement and then deterioration with the slow and exactly the opposite with the fast. S.'s ability at first decreases to practically the same degree with both rates, and then decreases much more with the slow.

From this comparison it is evident that, when considered by large steps, the results of four of the seven subjects (R., B., H., and S.) show greater deterioration in the case of the slow series. R. and B., indeed, show deterioration with the slow rate, whereas with the fast rate the ability to memorize actually improves. W.'s variations from the normal are probably too small to have any meaning at all. G.'s results present a very interesting point. It is evident that during the first part of the work for the day (which in the case of G. alone lasted two consecutive schedule periods in Group III, instead of one period) G. behaved like the majority of the other subjects. In other words, if G. had served as subject for only one period at a time her results would have

TABLE 3

Subjects	Dynamometer		Tactile Reaction		Addition		Multiplication		Repetitions Group II		Repetitions Group III		Repetitions in Sections Group III	
	s	f	s	f	s	f	s	f	s	f	s	f	s	f
G.	?	?	?	+	?	—	?	—	—	—	—	—	—	—
R.	+	—	+	—	—	—	+	—	—	—	—	—	—	+
B.	+	—	+	—	—	+	+	+	+	+	+	+	—	?
H.	+	—	?	+	—	?	+	+	—	—	—	—		
W.	+	—	+	—	—	?	+	+	+	—	+	+	+	—
K.	?	?	?	?	—	?	—	—	—	+	+	+		
S							+	+			—	—		

agreed with the others. The following question then arises: Is the change in G.'s ability during her second laboratory period a characteristic of G. alone, or would this change appear with the other subjects if they memorized series for two consecutive periods? This question, unfortunately, cannot be answered. The reasons for the peculiarities of K.'s results will be considered in the discussion of individual differences.

It is evident that the showing of the series, when grouped, often differs somewhat from the showing of the series treated separately. One reason for this, doubtless, is that many subjects learn the second and third of a day's series more quickly than they learned the first. When the series are taken separately this change in ability stands out as an improvement. When the series are grouped this increase in speed simply raises the average of the first group of series, *i.e.*, of the normal, and so makes any deterioration in the later series more marked.

Table 3 will show at a glance the general trend of all these results. It will be convenient for the reader to turn frequently to this table in reading the following paragraphs, which deal, largely on the basis of introspection, with the individual differences between subjects. Two of the signs which are used explain themselves. *Plus* (+) indicates *improvement,* and *minus* (—) indicates *deterioration.* The question mark (?) stands for *no decisive change in efficiency.*

Introspective Results

In this discussion, introspective statements of the subjects will first be summarized. An attempt will then be made to explain some of the individual variations in the numerical results in the light of this introspective testimony. The introspective statements of the subjects relate to the following points:—the subject's sensorial type of memorizing, method of grouping, use of auxiliary (mnemonic) associations, preference as to the rate at which the series were presented, and opinion as to which rate required greater concentration of attention and which was more fatiguing.

As to the image types to which the subjects belong:—B. and

S. claim imagery almost purely visual, although from the rest of B.'s introspection it seems probable that auditory-kinaesthetic imagery also was important.[8] W. appeared to use visual imagery except when the syllables "came mechanically," that is, when speech movements appeared to be preceded by no anticipatory imagery. G. visualized the syllables as patches of color on which occasional traces of written letters appeared in black. (G. has colored hearing in a marked degree). However, she also made constant use of auditory-kinaesthetic imagery which was more noticeable in the case of the rapidly repeated series than in the case of those slowly repeated and which served to distinguish between syllables of nearly the same color. This subject noted a tendency to grasp the last two or three syllables of a series merely in auditory-kinaesthetic terms and to recite them in virtue of a "kind of echo." H. "tried to visualize" the syllables which did not readily suggest auxiliary associations. The syllables which did suggest such associations she apparently learned in auditory-kinaesthetic terms, visualizing only the persons or objects which figured in the mnemonic devices. R. learned principally, and K. wholly, in terms of auditory-kinaesthetic imagery.

As regards grouping, all the subjects attempted, more or less, to grasp the syllables in sets shorter than the series. G., K., and S. always divided the syllables into groups of four. H. arranged the syllables in five groups, with four in the first group and two in each of the others. B. grouped the syllables, when she first began to serve as subject, but soon discarded this procedure. B., usually, but not always, grouped the syllables by fours, and W. grouped the first four together and, if the series happened to be particularly hard, also grouped the other syllables by twos. As regards spatial projection, all the subjects testified more or less to having visual schemes into which they fitted the syllables. G., except in Group III, visualized the syllables as arranged in a row from left to right; in Group III she purposely changed from a single horizontal line to three vertical columns each formed of four patches of color. This change was made in order to make the spatial position of the syllables more marked

[8] *Cf.* statement of preference for fast series on p. 180.

as compared with one another. The subject used this scheme as much in the fast series as in the slow, but had, in the case of the fast series, greater difficulty in fitting the syllables into the proper places. The subject said that, in the case of the fast series, putting the syllables into their proper places was like sorting dishes and setting them in their places upon the shelves of a china closet. H. thought of the syllables as arranged in a row from left to right. S. said she projected the syllables on the wall in three columns of four syllables each.

Auxiliary associations were used by all the subjects. These associations consisted in general of "stories" woven about the series and names of people connected with syllables having a somewhat similar sound. G. memorized to considerable extent without use of such associations but always fell back upon them in case of difficulty and was, therefore, more apt to use them in the case of fast series than in the case of slow. B. also used auxiliary associations more in the case of the rapidly repeated series. R. and H., on the contrary, used them more in case of the slowly repeated series.

With respect to preferences for one rate over the other, it should be noted that R., B., W., and K. preferred the fast series; G., S., and H., the slow. R. and H. were particularly strong in their preferences. The reasons given by R., B., W., and K. for the choice of the rapidly repeated series are as follows: R., "It takes no effort to associate the sounds. They run in together and don't need auxiliary associations." (R., it may be noted, often sighed, when learning slow series, and complained of the monotony.) B., "The fast series are easier to connect with a story." (The subject probably meant that the syllables in the fast series were more suggestive of a sentence.) W., "The words say themselves. With the slow rate I had more time to think, and as soon as I thought very hard, I was lost." K., "The slow series gave me time to forget." In the words of B., W., and K., there are indications of perseveration, kinaesthetic or auditory-kinaesthetic, in the case of the fast series. The reasons given by G., S., and H., for the choice of the slowly repeated series are as follows: G., "With the slow series I could fit the

syllables more easily into my scheme. Moreover, the syllables, which always appear in consciousness as spots of color, sometimes lag, and in the case of the fast series refuse to form in the mental field of vision before the metronome beat on which they are due. This experience is attended by very unpleasant organic sensations localized about the heart." G., however, confessed to having, not infrequently, the feeling of fright also, when learning the slow series. G. was ordinarily able to learn a slowly presented series in two repetitions and, realizing this fact, she felt considerable anxiety to keep the repetitions, at least on the average, at two. If, in any case, she exceeded two repetitions she tried desperately to learn the next series at the first hearing. S., "The slow series gave more time for recall and the experimenter pronounced the syllables more clearly at this rate." H., "I preferred the slow series because I had more time to work out my schemes for remembering." On the basis of these statements and of the other introspective data, it seems fairly clear that the subjects who prefer the fast series are, in general, those who are greatly assisted by kinaesthetic or by auditory-kinaesthetic perseveration, whereas those who prefer the slow series are, in general, those who rely chiefly upon visual imagery deliberately recalled.

It is evident that preference for one rate of memorizing over the other was not always coupled with better sustained efficiency in learning at the preferred rate. Although K. and W. both preferred rapid repetition, both showed greater deterioration when learning at this rate, and although H. and S. preferred slow repetition, these subjects showed a greater deterioration in learning the slow series. The deterioration of H. and S., in the slow series, may have been due to the fact that the difficulty of the task was not sufficient to keep their attention at high level. R., W. and K., who preferred the fast rate, expressly said that with the slow rate, their minds tended to wander. G., who preferred the slow series, showed in the first of her two periods greater deterioration with these series. G. explained her deterioration during the first period as follows: At the beginning of each sitting, when her mind seemed "like a freshly washed black-

board" on which every impression stood out distinctly, she could always learn a series with a relatively small number of repetitions (a *very* small number, usually two in the case of the slow series). However, when a number of series had been learned so that the mental blackboard seemed "clouded with erasures of every other series," the number of repetitions suffered an increase, which in the case of the slow series was large in relation to the very small number necessary at the beginning. (If the number of repetitions be two, an increase of one, the smallest increase possible, is an increase of fifty per cent.) Thus, two factors probably come into play in producing the appearance of greater deterioration during the first period in the case of the slow series: First, the arithmetical fact just stated, and second, the greater effort which the subject made to learn the slow series with a very small number of repetitions. This last circumstance may have brought about a genuine and considerable loss of efficiency.[9]

In regard to the feeling of fatigue, direct testimony is meagre. Only three times did any subject report feeling much fatigue at the end of the period. One day early in the year B. remarked that for the past two weeks she had been learning at the slow rate and that at that rate she had made a story, as she went along, to fit the syllables. When, however, on the day in question she had changed to the fast rate, she had become nervous, and at the end of the period felt weak and rather "seasick." The numbers of repetitions required for learning the successive series on that day were: 11, 6, 5, 6, 5, 5, 7, 5, 6, 8, 12, 7. G. reported marked fatigue on two days on which she learned twenty-four and twenty-eight series, respectively, at the fast rate. At the end of one of these periods this subject said that she felt weak and dizzy. The numbers of repetitions required for that day were: 5, 8, 4, 5, 5, 3, 4, 5, 4, 5, 4, 6, 6, 7, 4, 7, 5, 7, 8, 9, 4, 7, 3, 4. The day on which G. complained most of fatigue the following numbers of repetitions were needed: 3, 5, 8, 5, 6, 7, 4, 6, 3, 4, 9, 8, 6, 8, 7, 8, 6, 4, 5, 5, 8, 6, 4, 7, 4, 9, 8, 7. The subject began the work of this day in a condition of slight general fatigue. By the second set of six series her head began to swim and she felt more

[9] *Cf.* pp. 174 and 176 above.

and more weak and dizzy until the third set of six series when she felt faint and sick. In the fourth set she felt better than in the third, but toward the end began to feel numb and tremulous, and her heart began to beat irregularly. In the last set G. felt better, but was almost too exhausted to complete the arithmetic at the end. Symptoms of fatigue persisted two or three hours after the experimental sitting. In view of this experience of G., we may safely say that her deterioration in the second period when learning by rapid repetition was due to genuine fatigue. Although K. did not complain of being tired, yet she was in delicate health throughout the year and suffered from time to time with severe neuritis. It is also worth noting that W. had a nervous breakdown before the end of the year. K. and W., it will be remembered, both preferred the fast series and yet showed greater deterioration in these series, which obviously put a greater strain upon the attention. On the whole, the introspection of the subjects, taken together with the small amount of deterioration which their work at each sitting exhibited, seems to show that G. (in the second of her learning-periods) and possibly K. and W. were really tired but that they were the only subjects who were fatigued at all. Such loss of efficiency as occurred in the other cases, if due to fatigue, was not due to a fatigue marked by unpleasant subjective symptoms.

Data in Regard to Practice, Momentum, and Initial and Terminal Spurt

The main part of the discussion of the results of this investigation is now finished, but before summarizing the conclusions two other points of no small importance must be considered: (1) the influence of practice upon memorizing by the two rates of repetition, and (2) indications of initial spurt, of momentum, and of terminal spurt as they appear in the third group of experiments. It is impossible to trace these factors in Group II because at each sitting the memorizing was so broken up by the interpolation of fatigue tests.

Practice.—In the discussion of the method of making the experiments, the statement was made (page 161) that we tried to

use two rates of presenting the series which would take approximately the same total learning time. As the experiments continued it became evident that most of the subjects improved in memorizing at the fast rates more than they did at the slow rates. Inasmuch, as at the beginning of Group II, series presented at the different rates occupied practically the same total learning time, the differences in the times occupied in Group III show the extent of the influence of practice. In Group III, G. learned a slow series in about 129 seconds on the average, and a fast series in about 110 seconds. For the other subjects the corresponding figures are as follows: R., 187 and 149; B., 175 and 133; H., 237 and 224; K., 279 and 261; K., new method, 258 and 226; W., 230 and 186; S., 174 and 168. The difference in the total learning times necessary for the rapidly and slowly repeated series is very marked with all subjects except S. It must be remembered, however, that S. had served as subject at least ten weeks less than the other subjects had served, and therefore practice in her case naturally would be less marked. An important feature in the practice gained with the memorizing was improvement in apprehension, *i.e.,* in ability to grasp the syllables when presented to the ear. This improvement was particularly noticeable with the fast series. Therefore, the effect of practice was more marked with this rate. Thus, practice in some cases defeated the intention of the experimenters to equalize the actual expenditure of time in memorizing fast and slow series. The inequality of learning time for the two sets of series suggests an unfortunate possibility in regard to the figures which evince deterioration in efficiency. Some of the subjects showed greater loss in the slow series and some in the fast. It may be that the slow series tended to fatigue the subjects R., B., and W. in virtue of the long continuance of the strain upon the attention. This supposition is borne out by the fact that these subjects expressed a distaste for the slow series. On the other hand, the fast series may have tended to fatigue other subjects in virtue of the high degree of attention demanded and the emotional excitement involved in "catching" the syllables. The comparative degree of fatigue in the two kinds of attention-strain

may be a matter of individual differences and these individual differences may obscure the main issue in regard to the fatigue effects of memorizing by slow and by rapid repetition.

Initial Spurt, Gathering Momentum, Decreasing Momentum and Terminal Spurt.—Most experimenters seem to agree in spite of the varying methods used and the different conclusions drawn that mental activity shows a well-marked periodicity. There is no fixed normal type of daily rhythm, each person being apparently a law unto himself. Nevertheless, as to quantity, in any piece of steady work, most subjects exhibit the following stages: initial spurt, or else preliminary inertia with gathering momentum, decreasing momentum, and terminal spurt. If a pause or change of occupation is introduced in the course of the experiment, the work immediately after the interruption is often better and but very seldom worse than the work just before it. The quality and the quantity of work do not always vary in the same direction and degree. In general, in the period of decreasing momentum, the third of the four stages just mentioned, the changing relations between quality and quantity of work exhibit three chief moments: (1) quantity increases, quality decreases; (2) quantity also decreases; (3) with some subjects the quantity gets less and less, with others it increases under nervous excitement until exhaustion is reached. These phenomena can be traced only in the experiments of Group III and in this group only when the results are treated by the massing method.[10] In general, the slow series with all the subjects show the same trend in their variations—for the second of a set, a decided loss of ability; for the third, a decided improvement over the second (in the cases of H. and W. the results of the third series show higher ability than even the results of the first); for the fourth, loss of ability much less marked than that for the second series. G. and R. are the only subjects having a fifth or sixth series in a section. G.'s results show a yet further deterioration of efficiency for the fifth series, and an improvement for the sixth. R.'s results exhibit improvement for the fifth series. The results for the fast series show more individual variations than do those

[10] See pp. 172 and 175 above.

for the slow. All subjects except W. show loss of ability for the second series, and no subject shows marked recovery before the fourth series. With the fourth series the results of R., B., and S. show improvement over those of the second and third series, but the results of G., H., and W. show still greater deterioration. G. shows increase of ability with the fifth series and a slight decrease with the sixth. R.'s figures for her fifth series are indecisive.

These results therefore exhibit: (1) in the case of the slowly repeated series the stages of initial spurt, with most subjects, gathering momentum; and with G. and R., terminal spurt; (2) in the case of the rapidly repeated series with all except W., initial spurt; with G., R., B., and S., late in the group, gathering momentum, and with G. and R., decreasing momentum. It is, of course, possible that all the subjects would have shown all the stages if all the sections had contained enough series.

These results are important in showing the disadvantages of extraneous tests, for in the sets of series between the tests the subjects seem to pass through most of the stages of efficiency. These stages, particularly that of initial spurt, evident immediately after the extraneous tests, obscure the general trend of the fatigue effects which might appear in the course of the period.

Conclusions

The first conclusion to be drawn from the investigation as a whole is that the extraneous tests proved distinctly unsatisfactory. The arithmetic tests appeared most reliable, the multiplication tests showing fewer individual variations than any of the others. This may be due to the fact that this was the only one which was used after the subjects had had considerable practice. It is possible that the other extraneous tests would have exhibited fewer individual variations if they, also, had been used in Group III. It is puzzling that there should be deterioration in muscular strength and loss of efficiency in adding with most of the subjects, when the numbers of repetitions necessary for memorizing showed so little variation. We must conclude either that the variations in the strength of the grip and the speed of arith-

metical calculation were due to factors other than fatigue (a supposition which discredits their reliability as fatigue-tests), or that fatigue manifested itself in these extraneous tests before it was apparent even in the numbers of necessary repetitions.

A second conclusion is that the extraneous tests were not merely in themselves unsatisfactory but that they were also subversive of the main purpose of the investigation. Whatever advantages these tests may have in indicating fatigue is more than counterbalanced by the fact that they furnish change of occupation and retard the onset of the condition which they are supposed to test.

A third conclusion is that the subjects (G., H., and S.) who made much use of visual imagery in these experiments preferred the series learned by slow repetition, whereas the subjects (B., R., and W.) who appear to have been greatly aided by auditory-kinaesthetic perseveration preferred the series learned by fast repetition.

The fourth and main conclusion is negative, for as regards the chief issue our results are altogether indecisive. If we had not used the subjects G. and K., we should doubtless have supposed it perfectly clear that memorizing with slow repetition is more fatiguing than memorizing with rapid. The results of these two subjects, however, prevent the drawing of such a conclusion. There are three possibilities in the interpretation of the numerical results: (1) that none of the subjects were fatigued at all; (2) that all of the subjects were fatigued, but were affected in different ways; (3) that some only of the subjects were fatigued. From the consideration of our introspective results it is clear that the first of these possibilities was not realized, for B. and G. reported feeling greatly fatigued at the end of certain laboratory periods. The second of the possibilities—namely, that all the subjects were fatigued, but were affected in different ways—can scarcely be true, for the subject S. declared that neither rate fatigued her and that she would have enjoyed learning twelve more series each day. Furthermore, except in the cases already described in detail, the subjects practically never made remarks indicating that they were tired or even bored.

If, then, any reliance is to be placed upon the introspective testimony of the subjects, the conclusion must be drawn that only some of the subjects were fatigued. It is, therefore, evident that the second of the two main questions formulated on page 157 needs no discussion but must be answered with an emphatic negative. The fatigue of memorizing at a rapid repetition-rate is not so great as to cancel the time-saving effect of rapid repetition within the limits of a laboratory appointment lasting three quarters of an hour. Except for K. and for W. such fatigue as appears in a three-quarters-of-an-hour period is more evident in the case of the slowly repeated series than in the case of those rapidly repeated. Moreover, with W. and K. the fatigue (shown by the increase in the number of necessary repetitions) is far too small to counterbalance the gain in economy of time.

The final conclusion of the investigation is this: the problem is one which cannot be solved without much more experimental work. The results of those of our subjects who were certainly tired seem to show that rapid repetition is somewhat more fatiguing than slow, but before the statement can be substantiated it will be necessary to perform many experiments in which the periods of memorizing are long enough to tire the subjects. Such experimental conditions are hard to secure during the college year, for few of the available subjects are willing to be incapacitated for several hours from further academic work.

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A NOTE ON THE USE OF THE METHOD OF CONSTANTS IN EXPERIMENTS IN INTENSIVE SMELL DISCRIMINATION

By E. A. McC. Gamble

The experiments on which this note is based were made in the year 1913-1914 by Alice C. Forbes. The records numerical and introspective were completely destroyed in the Wellesley fire. Nevertheless, the results as remembered by the experimenter and by the writer of this note have a certain suggestive value, so that it seems worth while briefly to summarize them. The motive for the experiments was the desire to test the validity of a criticism made upon the method of the writer's effort to determine the applicability of Weber's law to smell.[1] At the suggestion of Zwaardemaker, the writer used Fechner's simple *method of just noticeable differences* which is really a rough form of the *method of stimulus production* and is, therefore, essentially "procedure with knowledge." In the course of the work she made a few experiments with the method of constants, for the purpose of determining its suitability, and definitely rejected it, because exhaustion seemed to make the second of the two compared stimuli almost invariably appear weaker than the first. After the publication of the work, the incompleteness of data unsubstantiated by the method of constants was pointed out by one of the critics of the paper.

The present experiments were made with the standard olfactometer of the ordinary form and with a fluid-mantle olfactometer of the form common in America, with which the subject breathes directly from an inhaling tube passing through the odorous cylinder. The substances used were, with the standard olfactometer, a combination of gum ammoniac and guttapercha and, in the case of the fluid-mantle olfactometer, vanillin. With one

[1] *The Applicability of Weber's Law to Smell.* American Journal of Psychology, (1898).

subject, who apparently has a vanillin defect, beeswax was used in place of vanillin, of course, with the standard olfactometer.

The subjects included the writer, five subjects of some general experimental training but little experience in smell work, and three untrained subjects.

The procedure each day included the following steps: (1) The condition of the subject's nasal passages was tested by examination of the "breathing spots." (2) The stimulus limen was determined on the basis of four trials with each nostril. (3) Taking for each nostril a stimulus of twice the liminal intensity, and taking for comparison a stimulus usually one-fourth stronger as many different determinations were made during a period of forty-five minutes as the intervals needed for rest and for the cleaning of the apparatus allowed. In testing the two nostrils a compensating program was used. The subjects were told that the two stimuli would never be equal and were forbidden to make equality judgments.

The results of these experiments certainly did not indicate that the exhaustion produced by the first of the two stimuli compared makes the use of the method of constants impossible. The second of the two stimuli was wrongly judged stronger than the first in quite as many cases as those in which it was wrongly called weaker. Moreover, three of the partially trained subjects gave so large a percentage of right judgments as to show the stimulus difference supraliminal. Nevertheless, the work left upon the experimenter and upon the writer the vivid impression that the use of the method of constants is, in the case of many subjects, undesirable. Three of the more painstaking subjects had great difficulty in getting distinct impressions of the intensity of the stimuli and were continually altering their method of judging, sometimes attending to one phase of the impressions and sometimes to another. These same subjects were constantly asking whether their judgments were right or not, and showed considerable annoyance at the "vagueness" of the stimuli which they were required to compare. In the case of subjects of this type, it would seem that training in smell discrimination by a "procedure with knowledge" should be preliminary to any use of the method of constants.